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EXPEDIENT SHELTERING IN PLACE: AN EVALUATION FOR THE CHEMICAL STOCKPILE EMERGENCY PREPAREDNESS PROGRAM

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This study examines the protective capacity of sheltering in place, a means of protecting the public if an accidental release of hazardous chemicals occurs. The report consists of two parts. The first is a review of the literature regarding the theory, practical parameters, and procedures for sheltering in place, including an analysis of sheltering instructions published by 11 organizations/communities. The second part presents results of tracer-gas experiments conducted on 12 buildings to determine the effect of expedient sealing measures upon the protection that can be provided by sheltering in place. Results of the experiments show that expedient sealing measures applied to a selected safe room substantially reduce air exchange rates. In using a bathroom with window as a safe room, placing a rolled wet towel at the base of the door and taping vents produced a 16.5% mean reduction in air exchange rate. Applied to a windowless bathroom or walk-in closet, this measures yielded a mean reduction of 30 to 32%. When tape was placed around the door and a sheet of plastic was taped over the window of a bathroom, the mean reduction was 34.3%.

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EXECUTIVE SUMMARY

This study examines the protective capacity of sheltering in place, a means of protecting the public if an accidental release of hazardous chemicals occurs. The first part of this report is a review of the literature regarding the theory, practical parameters, and published procedures for sheltering in place. The second part presents results of 36 experiments conducted on 12 buildings at Aberdeen Proving Ground, MD to determine the effect of expedient sealing measures upon the protection provided by sheltering in place.

Sheltering in place involves going/remaining indoors; closing all windows, vents, and doors; and turning off heating, ventilating, and air conditioning (HVAC) systems before the cloud of hazardous chemicals arrives. A tightly closed building will not keep out contaminated air completely but will allow it in slowly. After the hazard has passed, the closed building likewise retards the release of contaminants that have infiltrated; therefore, the occupants attain maximum protection by vacating the building or increasing its air exchange rate (opening windows and doors) immediately upon passage of the hazardous cloud.

Taping doorways and vents, placing plastic sheeting over windows, and laying a wet towel at the base of each door are additional measures that constitute what is called expedient sheltering. Applying permanent sealing measures, such as those used to weatherize homes, is referred to as enhanced sheltering. A fourth level of sheltering, pressurized sheltering, provides the greatest amount of protection but involves relatively large costs. Pressurized shelters are not known to have been used to protect the public in any chemical accidents.

Several studies have concluded that normal/expedient sheltering in place is a practical and effective means of protecting the public against transient chemical hazards. Sheltering's effectiveness has been demonstrated by successful application in actual emergencies. Sheltering procedures have been published and implemented by several U.S. communities in which industrial chemicals are stored or processed. Because of its application in industrial accidents, normal/ expedient sheltering in place has been identified under the Chemical Stockpile Emergency Preparedness Program as an option for the emergency response plans of communities near chemical agent stockpile sites and their future demilitarization facilities.

The principal advantage of sheltering is that it can be implemented more rapidly than evacuation. Its principal disadvantage is that the physical protection it affords is quite variable--sensitive to the duration of exposure, the tightness of the building in which shelter is sought, the timing of implementation, and the rates at which the materials in the building absorb and desorb the hazardous chemicals, as explained below:

- Protection decreases as the duration of the building's exposure to the hazardous cloud increases.

- The tightness of the building, stated in terms of its air exchange rate, is the most important variable for determining protection. This rate varies greatly among buildings and for a given building over time. It increases with wind velocity and with the

inside-outside temperature difference. It increases when heating, ventilating, and air conditioning systems are in use, and it can vary between upstairs and downstairs, from room to room, and from season to season.

- The rates at which materials in the buildings absorb and desorb a chemical as it passes through cracks and pores and comes in contact with materials inside the building affects the protection. There are, however, very little data available with which to accurately estimate this effect, which is referred to as filtering. Neglecting this factor provides a conservative estimate of protection.

- The timing of implementation strongly affects protection. Once the cloud passes, the closed building slowly releases the contaminants that have entered, so that beyond the point of passage, being inside presents a greater hazard than being outside. Protection factor, defined as the dosage outside divided by the dosage inside, approaches a value of 1 (zero protection) as the values for time of exposure and time of occupancy grow large--if there is no absorption or filtering of the agent. How rapidly this protection factor approaches 1 is determined by the tightness of the building and the ambient conditions. To illustrate this, if a building of 0.5 air changes per hour is exposed to a hazardous cloud for 15 minutes, it has a protection factor of 17 if the occupants exit immediately upon cloud passage. If they wait an additional 30 minutes to exit, however, the protection factor drops to 3.7.

Expedient sheltering is based upon an assumption that techniques can be applied rapidly, with little or no training, and with common household items to reduce substantially the air exchange rate of a room or building--and consequently to increase the protection. Applying room selection criteria and expedient sealing techniques to the room of the building best suited for sheltering may also reduce the variability of air exchange rate among shelters, thus narrowing the range of protection that can be achieved within a community.

In a review of 11 published instructions for sheltering in place, this study found that most sheltering instructions specified neither expedient sealing measures nor room selection criteria. The instructions also do not address what energy conservation studies have identified as a major leakage area, the wall-to-floor junction behind baseboards. Sealing such an area is considered a part of enhanced sheltering procedures rather than expedient sheltering.

To determine the effectiveness of two levels of expedient sealing measures in reducing the air exchange rates of rooms, 36 tracer gas experiments were conducted on 10 residential buildings and two mobile office trailers at Aberdeen Proving Ground, MD. Although these buildings are not considered representative of the broad range of buildings that could be employed for sheltering under the CSEPP, the results demonstrate that the expedient sealing measures do substantially reduce air exchange rates.

Applying the simpler of the two methods (placing a wet, rolled towel at the base of the door and taping any vents) to a bathroom with a window produced a 16.5% mean reduction in air exchange rate. Applied to a windowless bathroom or walk-in closet, this method yielded a mean reduction of 30 to 32%.

Applying a more extensive method--taping around the door and taping a sheet of plastic over the window--to a bathroom containing a window produced a mean reduction of 34.3%.

In the weather conditions that existed during tests of the 12 buildings, the calculated protection factors ranged from 15 to 68 for normal sheltering against a 10-minute hazardous exposure. Against a 1-hour exposure, the protection factors ranged from 3 to 13. With the best expedient room sealing measures, the calculated protection factors increased to a range of 39 to 101 for 10-minute exposure and to 7 to 17 for 1-hour exposure. These illustrations neglect any filtering effect and assume perfect implementation.

Although expedient sealing measures on selected rooms produced lower air exchange rates, there was greater variability in the rates among the sealed rooms than among the houses. This indicates that further gains in protection can be achieved by improving the sealing methods and/or sealing other leakage paths such as the wall-to-floor junction in the selected safe room.

This study identified a type of recirculating indoor air purifier with a carbon filter medium as having potential to improve the protection achievable through expedient sheltering. Such filter units, which are now widely available to consumers, are recommended for further evaluation.

A set of recommended procedures for expedient sheltering in place were developed during this study.

The following are the recommendations of this study:

- Develop estimates of the probable duration of an accidental release from a chemical agent demilitarization or storage facility. The most likely range of exposure duration must be defined to determine the specific applicability of sheltering to the CSEPP.

- Quantify the filtering effect. There are no data available on the rates of absorption of the chemical agents upon building materials, rates which are specific to each agent and the material to which it is exposed. Neglecting this effect yields low estimates of protection but also results in underestimating the period needed to purge the building after exposure.

- Test and evaluate the use of a consumer type indoor air purifier (recirculation filter containing carbon filter elements) to increase the protection afforded by sheltering in a selected room.

- Evaluate the combination of both enhanced sheltering measures (permanent sealing of areas such as the wall-to-floor junction) and expedient measures to reduce the air exchange rate of a selected safe room.

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PREFACE

The work described in this report was funded by the Chemical Stockpile Emergency Preparedness Program. The work was begun in March 1995 and completed in November 1995.

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EXPEDIENT SHELTERING IN PLACE: AN EVALUATION FOR THE CHEMICAL STOCKPILE EMERGENCY PREPAREDNESS PROGRAM

1. INTRODUCTION.

Sheltering in place is a means of protecting the public when there is an accidental release of hazardous chemicals, whether from a storage site, transport vehicle, or manufacturing facility for industrial chemicals. Originally developed as a protective action for nuclear accidents, sheltering in place has been employed in chemical accidents of varying severity since about 1985. It is considered an alternative to evacuation, the standard response in such emergencies.

To shelter in place, a person goes indoors or remains indoors; closes all windows, vents, and doors; and turns off heating, ventilating, and air conditioning (HVAC) systems before the cloud of hazardous chemicals arrives. A tightly closed building will not keep out the contaminated air completely but will allow it in very slowly. After the cloud passes, the closed building will very slowly release any contaminated air that has entered. Thus, the final step of the sheltering procedure is to open all windows and vacate the building as soon as the hazard has passed.

The amount of protection afforded by sheltering in place varies mainly with the tightness of the building and the duration of the hazardous exposure. Protection is greatest when shelter is sought in a tightly constructed building and when the hazardous exposure is brief. Protection decreases as the duration of the hazardous plume increases.

If there is adequate forewarning, additional measures such as sealing windows and doors with tape and plastic sheeting can be employed to further reduce the rate at which contaminated air infiltrates. Based upon the extent of such sealing measures, four levels of sheltering have been defined by the Oak Ridge National Laboratory (ORNL) in a study for the Chemical Stockpile Emergency Preparedness Program (CSEPP).[1]

- **Normal Sheltering** involves closing all windows and doors and turning off all HVAC equipment.

- **Expedient Sheltering** involves simple, rapid measures in addition to those of normal sheltering: placing a rolled wet towel at the base of the door(s); taping over ventilation ducts, electrical outlets or other openings; taping around doors; or taping plastic sheeting over windows.

- **Enhanced Sheltering** involves measures to reduce infiltration beforehand: caulking joints, applying weather strips and storm windows, or making other modifications to reduce infiltration, similar to those typically applied in weatherizing homes. These measures may be employed in combination with expedient measures.

- **Pressurized Sheltering** involves the use of special gas-particulate filter-blower unit(s) to pressurize a tightly sealed room, building, or portable enclosure with filtered air.

The filter-blower produces an outward flow (exfiltration) of clean air through leakage points, preventing the infiltration of contaminated air.

Pressurized sheltering provides the highest level of protection but involves relatively high costs. Pressurized shelters are not known to have been employed to protect the public in any chemical accident. Normal and expedient sheltering have been used in virtually all instances of sheltering in place.

Because it has been effective in industrial chemical accidents, normal/ expedient sheltering in place has been identified under the CSEPP as an option for the emergency response plans of communities near chemical agent stockpile sites and their future demilitarization facilities. Chemical agent munitions are currently in storage awaiting demilitarization at eight military installations in the continental U.S.--Aberdeen Proving Ground, MD; Anniston Army Depot, AL; Lexington-Blue Grass Army Depot, KY; Newport Army Ammunition Plant, IN; Pine Bluff Arsenal, AR; Pueblo Depot Activity, CO; Tooele Army Depot, UT; and Umatilla Depot Activity, OR.

The level of protection attainable through normal sheltering in place can be estimated if the building's air exchange rate--the rate at which inside air is exchanged with outside air is known. There is a large amount of data on the air exchange rates of various types of buildings as a result of studies on energy conservation and indoor air quality. There are very little data, however, on the effects expedient sealing measures have upon air exchange rates.

2. PURPOSE

This study was conducted to determine the state of knowledge on sheltering in place, to examine its potential as a protective action in an accidental release from a chemical weapons storage/demilitarization facility, to determine the improvement expedient sealing measures have upon protection, and to produce a recommended recipe card for sheltering.

3. BACKGROUND

3.1 Sheltering in Place as an Alternative to Evacuation.

Evacuation has long been the standard approach for protecting citizens when a chemical accident occurs. Over the last decade, however, sheltering in place has become recognized and accepted as a practical and effective alternative to evacuation. Its use has increased greatly since 1988, when a conference on in-place protection for chemical emergencies was held at Emmittsburg, MD to define the methods, requirements, and benefits of sheltering in place.[2] Since then, several local emergency planning committees (LEPC) have instituted programs for sheltering in place and have published instructions for sheltering in their communities.

One advantage of sheltering in place is that the protective action can be completed with less warning time than is needed for evacuation. Although evacuation is theoretically the safer alternative, it is not always so in practice. The amount of forewarning is the key in determining which is the safer alternative for a specific incident. To draw an

analogy from weather emergencies: Evacuation is always preferred in the event of a hurricane because the public can be warned well in advance, and the path and extent of the storm can be well predicted. Sheltering in place, however, is usually the only effective response for a tornado because warning times are typically short and the storm's path is unpredictable.

In chemical accidents, warning times can be very short, particularly when compared to the time needed to complete an evacuation. Evacuation routes can also lead through areas into which the hazardous plume already has travelled or is predicted to travel. There are several considerations in deciding whether sheltering or evacuation is the safer alternative in a specific situation. These are described in a 1988 report by the National Institute of Chemical Studies.[3] The approach of some LEPCs, however, has been to consider sheltering in place as the first option, because it takes less time than evacuation. Thus, authorities initiate sheltering while deciding whether to order an evacuation.

3.2 Factors Influencing the Protection Provided by Sheltering in Place.

Factors that determine the level of protection can be divided into two categories: physical factors and implementation factors. The former determine the theoretical or maximum physical protection achievable in a specific building. The latter, which involve behavioral influences, determine the practical capability of sheltering. This report focuses upon the physical factors.

3.2.1 Physical Factors.

The amount of physical protection a building can provide, that is, the protection achievable when implementation is 100% efficient, is determined by the:

- Air exchange rate of the building at the time of hazardous exposure
- Duration of the exposure and the time occupants remain in the building after the hazardous cloud has passed.
- Filtering that occurs as the contaminated air enters the building

Protection is normally stated in terms of protection factor, the ratio of the dosage outside to the dosage inside a protective enclosure. Dosage is concentration integrated over time; when the concentration is constant, dosage is equal to the concentration multiplied by the time of exposure. Dosage is usually stated in terms of mg-min/m^3.

Protection can also be stated in terms of a dose reduction factor, which is the inverse of protection factor.

$$\text{Protection Factor} = \frac{\text{Outdoor Dosage}}{\text{Indoor Dosage}} = \frac{1}{\text{Dose Reduction Factor}}$$

Once the protection factor of a building is known for specific conditions, the dosage in which sheltering can be safely applied can be determined by multiplying the protection factor by the dosage at which physiological effects are known to occur for each specific chemical agent.

3.2.1.1 **The Air Exchange Rate of the Building.**

A building employed as a chemical shelter can be likened to a leaky boat. It can be used for short excursions but should not be left in the water for long periods. The safety of its use is governed by the rate of its leaks in relation to its volume and the length of time it is to be in the water. Although the ventilation of a building is more complex, the protection a building provides against airborne hazards is similarly determined: by the rate of air leakage relative to its volume and the length of time the building is in the chemical cloud.

All buildings, even those tightly constructed, have air leakage. This is commonly expressed in terms of the air exchange rate, the rate of uncontrolled exchange of air between the indoors and outdoors through cracks, pores, or other openings connecting the living area with the outdoor environment. This rate is stated relative to the volume of the building as the number of air changes per hour (ACH).

The air exchange rate determines how rapidly airborne contaminants infiltrate the building from the outside and how rapidly they are purged from the building once the outside air is no longer contaminated. If the building's air exchange rate remains constant, it will take longer to purge the contaminant after the cloud has passed than it took for the contaminant to enter the building, and at some point during or after cloud passage, the concentration inside will exceed the concentration outside.

The equation for protection factor of an enclosure that has air leakage (an air exchange rate greater than zero) is found in several references; reports by Englemann[4], and Lewis[5] are three that explain its derivation. In this equation, shown below, protection factor is a function of three variables: R is the air exchange rate of the building in ACH. T is the time the building is exposed to the hazardous cloud, in hours; and t is the time of occupancy, in hours, beginning upon the arrival of the hazardous cloud.

$$\text{Protection Factor} = \frac{RT}{RT + e^{-Rt} - e^{R(T-t)}}$$

There are two different time variables because there are two distinct phases of the process. The first phase (time T) is when the cloud envelopes the building, during which the interior concentration increases. The second phase (time t - T) is after the cloud passes, during which the interior concentration decreases as contaminants that have entered are released from the building.

The protection factor is highest when T equals t, that is, when the occupancy time is equal to the time the hazardous cloud is present around the building. In this case, the occupants exit as soon as the cloud passes, and the third term in the equation becomes equal to 1. As the value of t grows large, the second and third terms approach zero, and the protection factor approaches 1. This means that the dosage to which occupants are exposed inside will eventually equal the dosage accumulated outside if they do not, after cloud passage, exit into clean air or increase the air exchange rate by opening windows and doors.

To illustrate the effects of exposure time (T) and occupancy time (t) upon protection factor, the equation above was used to calculate the protection factor of a building

having an air exchange rate of 0.5 ACH. These calculated protection factors, shown in Table 1, illustrate the importance of taking steps to vacate or aerate the building immediately after cloud passage. With an exposure time of 15 minutes, a protection factor of 16.7 is achieved with immediate exiting; that is, the occupants are exposed to about 1/17th the hazardous dosage they would have been exposed to in remaining outside. When the occupants wait an additional 30 minutes before vacating the building, however, the protection factor decreases markedly; the exposure dosage is about four times greater.

Table 1. Illustration of Protection Factors Calculated for a Building of 0.5 ACH as the Exposure and Occupancy Times Vary.

Time Building is Exposed (T)	Time of Occupancy, From Cloud Arrival (t)	Protection Factor
15 min.	15 min.*	16.7
15 min.	45 min.	3.7
1 hr	1 hr*	4.7
1 hr	1½ hr	2.6
2 hr	2 hr*	2.7
2 hr	2½ hr	2.0

*In the three examples marked by an asterisk, occupants vacate the building as soon as the cloud passes; that is, T and t are equal. In the other three examples, the occupants wait one half hour before exiting. Note: This example neglects the effect of filtering, absorption of the chemical vapor by the building, which would increase protection factors.

Chemical warfare experiments conducted in 1948-49 demonstrated that the dosage inside a building approaches the dosage outside if there is no substantial loss of agent as a result of absorption by materials in the building. In exposing a building (of air exchange rate 1 ACH) to a smoke cloud for durations of 15 to 30 seconds, the dosage accumulated inside the building over a one-hour period ranged from 50 to 80% of the outside dosage, even though the inside concentration was only 1/100th of the outside concentration.

The effect upon concentration has also been examined in Canadian studies.[6] A closed building dampens the rapid fluctuations in concentration caused by the random variability inherent in atmospheric diffusion, protecting the occupants from exposure to high peak concentrations. This effect is significant in protecting against agents for which the concentration, rather than the cumulative dosage, determines the physiological effects. For the chemical warfare agents of the CSEPP, however, the effects are a function of dosage, rather than maximum concentration.

The protection factor equation above is based upon the assumption that as long as the chemical cloud is present, its concentration is constant. Other assumptions in its application are that the building and all its leakage areas are uniformly exposed; that the air is well mixed inside the building; and that there is no filtering effect. These assumptions,

particularly with regard to absence of filtering, result in a conservative estimate of protection; that is, the equation gives a *lower* protection factor than would actually occur.

3.2.1.2 **Filtering Effect.**

Filtering occurs when the chemical vapor/gas is absorbed or deposited as it passes through cracks and pores while entering the building or as it comes in contact with materials inside the building--particularly porous materials such as draperies, carpets, and other fabrics. The effect of filtering has been examined in at least four studies on sheltering (by Birenzvige[7], Stearman[8], Engelmann[4] and Christy and Chester[9]), and it has been shown to increase the protection factor.

Filtering is neglected in most estimates of protection afforded by sheltering in place because there are very little data on the rates of absorption and desorption of chemical vapors/gases and because filtering is less important than the air exchange rate in determining the amount of protection. Rates of absorption and desorption are specific to each combination of chemical agent and the material by which it is absorbed. Only one study is known to have quantified the rates at which a fabric absorbs and desorbs chemical warfare agents; it examined such rates for the U.S. Army battledress uniform exposed to soman and mustard vapors.[10]

To estimate the effect filtering has upon the protection a building provides, one must apply estimates of several variables: the rate at which the agent vapor is absorbed by the materials of the building (stated as deposition velocity), the rate at which it desorbs, the surface area of the paths (cracks and pores) through which it enters the building, and the surface area inside the building.

Using deposition velocity estimates ranging from 0.01 to 0.1 cm/second, Birenzvige[7] calculated that for a three-hour exposure, absorption would reduce the dosage to which occupants of a 1 ACH building are exposed by 35% if the deposition rate is 0.01 and by 85% if the deposition rate is 0.1. These estimates, however, are based upon a desorption rate of zero; that is, it is assumed the agent would be retained indefinitely. Such is not likely to be the case, however, as a portion of what is absorbed will eventually desorb. Thus, the effect of desorption is to introduce a lag time and consequently to decrease the dosage to which occupants are exposed before they vacate the building.

3.2.1.3 **Variability in Air Exchange Rates.**

Air exchange rates vary widely, not only from building to building but also for a given building over time. The protection afforded by sheltering in place therefore is also highly variable.

"The natural variability of construction causes modern houses in both Canada and the U.S.A. to vary in leakiness by about a factor of two above and below the mean value," notes Dr. D.J. Wilson of the University of Alberta, who has done extensive research on sheltering in place. "These results indicate that the protection afforded by sheltering indoors will be highly variable within a neighborhood of houses exposed to a toxic release."[11]

Various studies on energy conservation and indoor air quality have produced a large source of data on air exchange rates of U.S. buildings, and these provide an estimate of the range of exchange rates that can be expected. One study published in 1987 showed the range for low-income houses and modern houses to be about 0.2 to 5 ACH during the heating season, with a median rate of approximately 0.7 ACH.[12]

The natural air exchange rate is *not* a constant value for each building, however. It can change continually with a number of variables, some of which are controlled by the basic procedures of sheltering:

- **Wind velocity and direction.** The air exchange rate increases as wind velocity increases. Wind produces a pressure difference between the outside and inside, causing air to infiltrate through the windward wall and exfiltrate through the leeward wall. This flow results from both the positive pressure difference on the windward side and the negative pressure created by wake effects and flow separation on the leeward side. The wind direction with respect to the location of leakage points--windows, vents, cracks, and other openings--is also significant in determining the rate of air exchange.

- **Inside-outside temperature difference.** As the temperature difference between inside and outside increases, the air exchange rate increases. Differences in mean indoor and outdoor temperatures, whether positive or negative, lead to different pressure distributions with height on the indoor and outdoor faces of the walls. These differences impose a pressure difference across cracks, pores, or openings that connect the indoor and outdoor environments. This is referred to the stack effect or buoyancy driven component.

- **HVAC systems.** If any HVAC ductwork is located external to the living area (in attics, garages, or crawl spaces) it can be a major pathway for infiltration, and the air exchange through such ducts increases when the central HVAC blower is operating. A study of 31 homes in Tennessee found that the rate of air exchange nearly doubled when the central blower was operating: The mean value was 0.78 ACH with the blower on and 0.44 ACH with the blower off.[13] In a study of mobile homes, this difference was even greater: 2.3 to 2.7 ACH with the blower on and 0.8 ACH with it off.[14]

- **Combustion.** With the exception of mobile homes, most U.S. residential buildings heated by combustion (by oil, natural gas, wood, or coal) have furnaces or stoves that draw combustion air from the living area. The combustion process induces a flow of air from the outside, through the living area, and out the chimney.

- **Seasonal variations**. Air exchange rates are highest in winter and the lowest in summer as a result of contraction and expansion of building materials as moisture content changes with relative humidity. A study of homes in the U.K. found this seasonal variation to be on the order of 40% for some houses.[15] One study of American houses found rates about 22% lower in the summer than in the winter.[16] A second study on two U.S. houses found the difference to be about 20%,[17] and a third found air exchange rates four times greater in winter than in summer.[18]

- **Upstairs/downstairs.** Air exchange rates can be substantially higher downstairs than upstairs. A study of two houses over a one-year period, found the rates to

range from 0.07 to 0.32 ACH upstairs, and 0.14 to 1.69 ACH downstairs.[18] Downstairs rates were from 4 to 7 times higher than upstairs rates in one house that had not been weatherized. The study also found that when measurements were made with the HVAC blower turned off to minimize airflow among zones of the house, the air exchange rate downstairs was about 0.1 ACH higher than upstairs. The high downstairs rates during winter were consistent with the expected upward airflows due to inside-outside temperature differences. Other studies suggest that the downstairs air exchange rate is more closely related to the temperature difference, and the upstairs rate is more closely related to wind speed; the upstairs typically has a greater exposed perimeter wall area with windows and other potential leakage sites.

• **Room variations.** Variation in air exchange rate among rooms results from differences in building design, construction practices, orientation with respect to the wind, and location with respect to perimeter walls. The number of windows, doors, and vents in a room, and the configuration of each are important. One analysis suggests that a room without windows or doors might have a rate of 0.5 ACH, one with a door or window on one side would have a rate of 1 ACH; on two sides, 1.5 ACH; and three sides, 2 ACH.[3]

• **Method of measurement.** Values for air exchange rate vary not only with the conditions and building configuration at the time of measurement, but also with the method of measurement. Two different methods are commonly used, as defined in standards of the American Society for Testing and Materials:* fan pressurization and tracer gas dilution. With the former, air leakage is determined at a given internal pressure. The latter, which involves releasing a tracer gas inside the building and measuring the rate at which its concentration decreases, determines the natural air exchange rate at the conditions existing at the time of measurement. Measurements by this method can vary over a range of 5 to 1 for a single house, depending upon the weather conditions.[19] There is no simple formula for relating the data obtained by the two different methods. The pressurization method applies pressure equally to all walls and surfaces, while the forces due to wind or temperature differences are asymmetrical. One rule of thumb is that the rate under natural conditions is approximately 1/20th the airflow rate (in ACH) needed to pressurize the building to 50 Pascals. This roughly predicts only a single infiltration rate independent of wind and temperature differences.

It is standard practice to have the central HVAC fan operating (for air mixing) when taking measurements by the tracer gas dilution method. As noted above, this can substantially increase the rate of air exchange. Thus, most data acquired by this method may not accurately reflect the exchange rate of building as it would be when used for sheltering.

In studying the effectiveness of sheltering against a radiological hazard, Engelmann[4] developed estimates of air exchange rates that could be expected for residential buildings under conditions approximately those of sheltering. By selecting only data that had been acquired with furnace and fans off and with no occupant activity (such as opening and

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*ASTM E779, "Standard Test Method for Determining Air Leakage Rate by Fan Pressurization" and ASTM E741, "Standard Test Methods for Determining Air Change in a Single Zone by Means of Tracer Gas Dilution", American Society of Testing and Materials, 1916 Race St., Philadelphia, PA, 19103.

closing doors), he developed graphs of air exchange rates as a function of wind speed and indoor-outdoor temperature difference. These show an apparent minimum exchange of 0.1 ACH for tight houses and 0.3 ACH for leaky houses. Although his analysis indicates that air exchange in the leakier houses configured for sheltering would be significantly less than that indicated by the larger body data on exchange rate, it is based upon too few data for conclusions about the full range of protection expected in sheltering.

The effect of wind and inside-outside temperature differences are simpler to account for than the effect of HVAC operation. Several models have been developed for determining the effects of wind and temperature differences.[19] However, it is important to note that the effect of wind is also to reduce the concentration of a chemical cloud, to disperse it, and to cause its more rapid passage. For example, modeling has shown that at 10 mi/hr wind speed, the dosage and maximum concentration at a point directly downwind of a mustard artillery burst are about 5 to 10% of the values that occur at ½ mi/hr.[20]

3.2.2 **Measures to Reduce the Air Exchange Rate.**

How much can the sealing measures normally applied in weatherization of buildings be expected to reduce the air exchange rate? Data regarding this provide an indication of reductions that are possible with *enhanced* sheltering, for comparison to those of expedient sheltering.

A study of Canadian homes found that applying weatherstripping and caulking in the following ways produced a median reduction in air leakage of 31% for conventional houses: weatherstripping exterior doors and windows; caulking exterior doors, windows, electrical plugs and switches on exterior walls, ceiling lights, and electrical openings in the attic, plumbing stacks, vents, and ducts passing through attics, fireplace and furnace chimneys in the attic, cracks along interior partitions, the attic hatch, cracks between concrete walls and subfloor, floor joist area, perimeter of mail/coal chutes, general cracks and openings in walls.[21]

In testing two matched homes, it was shown that air exchange rates could be lowered 22% in summer and 24% in fall with the following measures: Applying sill plate sealer and caulking between masonry and frame wall; adding a vapor barrier in the upper level floor overhang and on the inside foundation/knee wall; sealing electrical outlets and switch boxes; sealing pipe and cable penetrations through wall top plates; caulking windows; adjusting exterior doors; weatherstripping the attic access panel; adjusting garage doors; sealing the wood stove insert plate and mouldings; and adjusting exhaust fan dampers.[22]

With regard to the vapor barrier, Wilson[11] concluded: "The most important factor that influences leakage area is whether a house has an air-vapor barrier in the walls and ceiling. As a rough estimate, houses built in cold climates after 1960 usually have vapor barrier, while older houses do not."

In examining the cost of such sealing measures, a study published in 1988 by Chester[23] estimated that to reduce the whole house air exchange rate from 1 ACH to

0.25 ACH would cost approximately $1,000 per house (1988 dollars). To apply sealing measures to just one room of the house, the estimate was $200.

3.2.2.1 **Expedient Sealing Measures.**

The procedures of expedient sheltering are based upon an assumption that there are techniques that can be applied rapidly, with little or no training, and with common household items to significantly reduce the air exchange rate of a room or building.

It is postulated that by applying room selection criteria and expedient sealing techniques to one room of the building best suited for sheltering, not only can a higher protection factor can be achieved but also the variability of protection--that is, the variability of air exchange rate from building to building--can be reduced. A practical advantage of applying sealing measures to a single room is that they can accomplished more rapidly and simply than if they are applied to the whole house.

There is little data on the effectiveness of expedient methods of room sealing. In evaluating methods of emergency protection against aerosols, ORNL found that a room sealed with polyethylene sheeting and tape provided a protection factor at least 10 times greater than the house as a whole when challenged with spores of *Bacillus globegii*.[9]

The ORNL study also examined the effectiveness of expedient sealing measures in experiments conducted on 13 dwellings in East Tennessee in 1989 using the tracer gas dilution method.[1] Three experiments were conducted in each house to measure in sequence the air exchange rate of the whole house, the rate of the selected room sealed by wet towel under the door, and rate of the same room sealed by tape and plastic sheeting. Although this approach of taking the three measurements sequentially was subject to uncontrolled temporal variations in the air exchange rate, it showed that when the doors, windows, plumbing, and electrical fixtures were taped, the exchange rate of the room was on the average only 45.6% of the air exchange rate of the room sealed with only a wet towel at the base of the door.

The ORNL study also yielded time and habitability data. To tape and seal the selected room took from 2.3 to 38.6 minutes with an average of 15.7 minutes. Simply closing the doors and windows of the house and turning off the HVAC, which are the steps of normal sheltering, took 3.2 minutes on the average.

Results of these trials showed habitability of the sealed rooms to be of some concern. During the experiments, which were run in the months of June and July, the temperature in the sealed room rose an average of about 2°F and the relative humidity rose by about 12%, on average, over the sheltering period of 40 minutes, and the occupants became uncomfortably hot.

3.2.3 **Implementation.**

Implementation factors--behavioral and technical influences unrelated to the protective capability of the building used for sheltering--are important in determining the protection achieved by sheltering in place. These are discussed only briefly here, as they are

covered in detail in several documents on protective actions.[1,2,3,24] To implement sheltering in place requires the capability to:

- Ensure the residents know how to take the protective action
- Determine rapidly that a release has occurred
- Determine the areas that may be affected by the release
- Communicate a timely warning to all people in the affected areas
- Communicate the appropriate time to vacate in-place shelters

Only the fifth of these capabilities is specific to sheltering in place. The others listed above must be a part of the emergency response system whether the protective action is evacuation, sheltering in place, or use of individual protective equipment. The importance of the fifth capability--communicating to the community that the hazard has passed--can be seen in the protection factor estimates of Table 1. In the case of an evacuation, the all-clear notice can be delayed to ensure the hazard has abated; delaying the return of the evacuees to their homes increases the margin of safety. In the case of sheltering, however, delaying the all-clear signal for residents sheltering in place beyond the actual moment that the hazard has passed *decreases* the safety of those sheltering. Delays in issuing the instructions for sheltering--whether to initiate the action or to vacate shelters--decrease the effectiveness of sheltering. If a person receives some exposure before getting into a shelter and remains in the shelter long after cloud passage, it is possible to receive a greater dosage than might have been received without sheltering.

3.3 Current Procedures for Sheltering in Place.

In a 1989 literature review, the ORNL found eight instances in which sheltering in place had been implemented for protection against a chemical release.[1] Some of these can be described as passive applications; that is, the chemical release occurred when residents in the affected area were indoors with windows and doors already closed (such as on a winter night), so the decision to shelter in place required no action by the residents.

There has been no subsequent survey to compile a current list of applications of sheltering; however, presentations at the September 1995 Conference on Protecting the Public[24] in Charleston, WV, indicate that the number has grown markedly. Contra Costa County, California, for example, has employed sheltering in place seven times in five years, including a July 1993 accident involving the release of 12,000 gallons of oleum (presentation by Tracey Hein-Silva, Contra Costa County Health Department, Sept 21, 1995). As a result of this release, 22,000 people sought medical attention at hospitals and 22 were hospitalized; however, 100 employees who sheltered in place for more than three hours 3,000 ft directly downwind of the release showed no effects of the chemical. Sheltering in place is also known to have been employed, though without actual exposure of chemical agents, to protect Israeli citizens from the threat of missile-delivered chemical agents during the Persian Gulf War in 1990-91.

Instructions for sheltering in place have been published and distributed by several communities where hazardous industrial chemicals are stored or processed. One

organization, the NICS, has made available a sheltering kit, which includes sealing materials and an instructional videotape.

Instructions for sheltering in place published by the following communities or organizations were reviewed during this study.

- National Institute for Chemical Studies: video tape and technical report
- American Red Cross: brochure
- Michigan Department of State Police: pamphlet
- Deer Park, TX: information on community calendar
- Charleston/Kanawha County, WV: information page in phone directory.
- Louisville/Jefferson County, KY: brochure
- Bucks County, PA: brochure
- Oak Ridge National Laboratory: technical report
- Contra Costa County, CA: brochure
- Tooele County, UT: information on 1996 Emergency Preparedness Calendar
- Pont-de-Claix, France: brochure

The steps in each of these procedures are listed in Appendix A and are summarized in Table 2.

3.3.1 Methods Specified in Published Instructions for Sheltering.

Apparently, most of the sheltering instructions published in the U.S. are based upon those presented in technical reports by the NICS[3] and ORNL.[1] There are significant differences among them, however, as Table 2 shows. Only three steps are common to all 11 procedures reviewed, and these three are the steps that constitute normal sheltering in place: closing windows and doors, turning off HVAC, and staying indoors while listening to radio or television for instructions.

The omission of some steps may reflect an effort to simplify the instructions so that they can be understood and performed easily by the average person. Doing so, however, implies judgements on the value of those steps omitted. The following is a brief discussion of some of the measures specified in the published procedures. Some are addressed because of their importance, others because they are of questionable benefit for protection against a potential release chemical warfare agents.

Table 2. Summary of Measures Specified in Published Guides or Reports on Sheltering

Measures Common to All
- Close all windows and doors.
- Turn off all fans, heating, and air conditioning systems.
- Stay in the room and listen to radio or TV until told to evacuate.

Sealing Measures Found in Some
- Place wet towels in the cracks under the doors. [a,c,g,h,i]
- Close the fireplace damper.[a,b,e,f,i,k]
- Tape plastic (such as drop cloths) over windows.[h]
- Tape outlets or electrical fixtures. [g,h]
- Tape around doors, windows, exhaust fans or vents.[a,h] Cover cracks with tape.[c]
- Use the plastic garbage bags to cover windows, outlets, and heat registers.[a]
- Block out all outside air.[d]
- Lock windows (they seal better when locked).[f,h,i,k]
- Close as many internal doors as possible in the home or building.[f,g,j,k]
- Use tape and plastic food wrapping, wax paper, or aluminum wrap to seal bathroom exhaust and grilles, range vents, dryer vents, and other openings to the outdoors.[f,i]
- Seal plumbing and cabinets.[g]
- Switch inlets to closed position, seal gaps around window air conditioners with tape and plastic sheeting, wax paper, aluminum wrap.[f] Seal all gaps with plastic sheeting or wrap.[k]

Room Selection Criteria Found in Some
- Use an above ground room (not the basement).[a,k]
- Select an interior room, no or few windows, no plumbing fixtures if possible, no window air conditioners, and at least 10 sq ft floor area per person.[g]
- Use leeward area of basement and seal cracks and openings for extra protection (Do not use basements if toxic gases are heavier than air).[e]
- Preferably use a room with no or few windows.[a,c]
- Use a room away from the factory (source)[j]. Use a central room.[k]

Complementary Protective Measures Found in Some
- In some cases, cover your mouth and nose with a damp cloth.[a,b,c,e,f,i,j]
- In the bathroom, close door, turn on the shower in a strong spray to "wash" the air.[f]
- Take frequent shallow breaths and stay calm.[b] Remain calm, relax, and stay immobile.[g,j]
- Don protective clothing to vacate shelter.[g]
- If you feel a prickling sensation on exposed skin, wash with water.[j]

Measures for Minimizing Induced Leakage Found in Some
- Minimize the use of elevators.[f,k]
- Ensure all ventilation systems are set to 100% recirculation.[f] Use recirculated air only.[k]

Measures to Ventilate After Cloud Passing Found in Some
- At the "all clear" open windows and doors, ventilate the building, and go outside.[c,e,g,h,j]

Other Measures Found in Some
- Keep the phone lines open for official use.[b,d,i]
- Have a kit of supplies (radio, flashlight, food, water, medicines, duct tape)[a,e,g,h]
- Have a ladder, stool, or chair, available.[g]
- Keep your pets inside [c,f,i,k]
- If danger of explosion, close curtains, window shades, blinds; stay clear of windows.[a,f]

a - American Red Cross; b - The City of Deer Park, TX; c - Charleston, Kanawha County, WV; d - Louisville/Jefferson County, KY; e - Michigan State Police; f - Bucks County, PA.; g - ORNL Technical Report; h - National Institute of Chemical Studies; i - Contra Costa County, CA. j - Poin-de-Claix, France. k - Tooele, UT.

3.3.1.1 **Turning off HVAC Systems.**

Turning off all HVAC systems is critically important, whether these are recirculating or ventilating, central or window-type systems (although two sets of instructions listed in Table 2 inappropriately state that the recirculation fan can be left on). The HVAC affects the protection afforded by sheltering in three ways. First, turning off the central/ recirculation fan reduces the induced leakage as discussed in Section 3.2.1.2. Second, if a furnace or stove which draws combustion air from the living area is in use, turning it off eliminates the infiltration induced by combustion. Third, if sheltering takes place during the heating or air conditioning season, turning off the HVAC will reduce the difference in indoor and outdoor temperatures and consequently the infiltration caused by the stack effect. This last effect would not likely to be as great as the other two in sheltering situations, because changes in building temperature would occur slowly and thus be small in magnitude over the period in which sheltering would likely take place.

3.3.1.2 **Selecting and Sealing a Room for Sheltering.**

Expedient sealing measures and room selection criteria in procedures published by the NICS[3] and ORNL[1] are based upon data from energy conservation studies regarding the most common pathways of infiltration. Such data show a wide range in the relative component leakage, as would be expected with the variations that exist in construction practices, building design, and the configuration of components.

One study of Texas houses showed the six areas of largest air leakage to be the sole plate (junction of walls and floor, behind the baseboard), accounting for 24.6% of the leakage; electrical wall outlets, 20.3%; air conditioning ducts, 13.5%, exterior windows, 11.8%; fireplace with damper closed, 5.5%; range vent (dampered), 5.2%.[25]

In another study, an analysis of 19 houses with fireplaces, a different distribution of leakage was found: sill and wall/ceiling joints, 31%; HVAC systems, 15%; fireplace, 14%; pipes, 13%; doors, 11%; windows, 10%; vents, 4%; and electrical outlets, 2%.[26]

The two studies have very dissimilar values for electrical outlets but show the other major pathways to be of the same relative magnitude: sole plate or sill plate, HVAC systems, fireplace, pipe penetrations, windows, doors, and vents. Ideally, the room selected for sheltering should have as few of these pathways as possible, and sealing measures should be focused upon the areas of the greatest leakage potential to produce the largest reductions in air exchange rate in the least time.

Most published procedures reviewed for this report do not, however, address these leakage pathways, either with expedient sealing techniques or room selection criteria. Selection criteria related to leakage appear in only three of the published procedures. Even the simplest measure of placing a wet towel at the base of the door appears in only half the procedures. Other expedient techniques for reducing infiltration are omitted from most: Closing the fireplace damper is addressed in five, taping vents in four, taping windows in three, taping electrical outlets in two, and taping plumbing penetrations in one. Measures to reduce leakage through the two major pathways--the sole plate/ sill plate and HVAC ducts--are not specified in any of the procedures reviewed.

Leakage through the sole plate occurs because wallboard does not usually extend to the subfloor and thus is not sealed to the sole plate or subfloor. This allows air to pass under the wall from behind the baseboard trim. The technique for reducing air leakage at the sole plate is to remove the baseboard temporarily and cement a 3-inch wide strip of fiberglass along the wall-to-floor joint. A similar path of infiltration is along the sill plate, which rests atop the concrete foundation wall. In retrofitting a home, leakage through this interface is reduced by caulking.

To reduce leakage through the HVAC ducts external to the living area, one must enter the attic or crawlspace and apply tape to the joints of the ducts. None of these three procedures can be considered expedient measures; however, they are among those techniques to be applied for what is described as enhanced sheltering.

The ideal room for sheltering is one which has no outside walls, no windows, no vents, one door, lighting and electrical outlet for radio or television, and adequate room for the expected number of occupants. Such a room does not exist in most houses. In a typical dwelling, the only rooms that may have no outside walls and no windows are bathrooms and walk-in closets. However, building codes require that a bathroom must have a ventilation fan if it has no window.

There are two other selection criteria found among the published procedures: that the room should be on the leeward side of the building and that it should not be in the basement. The former is desirable in that the interior concentration on the leeward side will lag that of the windward side. Avoiding use of the basement assumes that the agents will eventually settle into the lowest point of the house, the basement. Anecdotal data on mustard attacks of World War I indicate that this would occur.[20] A report by the NICS[3] indicates that there is no advantage to sheltering in upper floors because of differences in air exchange rates between the two floors. However, as is noted in Section 3.2.1.2, there are data showing that the second floor would be preferable to the first floor because the air exchange rate is likely to be lower on the second floor.

Room selection criteria developed by ORNL are summarized in Table 3.

Table 3. Room Selection Criteria Developed by ORNL[1]

- At least 10 sq ft per person

- Relatively small, with no outside walls, on ground floor
  or, if not available, a small room with no windows
  or, if not available, room with smallest number of windows and doors

- Avoid rooms with window air conditioners, windows that leak, vents to outside (such as automatic dryer vents and circulation vents).

- Avoid rooms with exhaust vents that automatically start when the light is turned on. If all these elements are the same for two rooms, chose the room that is free of plumbing fixtures.

This table presents some of the criteria in order of importance; however, because rooms in a typical dwelling are not likely to fit this or other criteria easily, room selection would appear to be a process too complex for the average person to perform correctly.

3.3.1.3 **Placing a Wet Rag over Nose and Mouth.**

This complementary protective action, which appears in 7 of the 11 procedures, is essentially the same expedient employed by soldiers caught in the first chemical attack of modern warfare, a chlorine release in 1915. Experiments at Fort Detrick, MD, have shown that a handkerchief folded to eight layers or a bath towel folded to two layers can reduce the inhalation of aerosol by 85 to 90% whether the cloth is wet or dry.[27] However, this would have only a small effect against gases that hydrolyze well (such as chlorine or phosgene) and virtually no effect against the chemical agents in the U.S. stockpile. (Mr. Robert Morrison, ERDEC Research and Technology Directorate, personal communication).

3.3.1.4 **Turning on the Shower.**

Another complementary action, turning on the shower appears in one of the published sheltering procedures. With the shelter established in a bathroom, there are two effects that can be achieved by turning on the shower. Running the shower with a closed drain creates a small outward flow of air by displacing the air in the room at the volumetric flow rate of the water. Secondly, the small water droplets have a scrubbing effect and can remove airborne contaminants from an enclosure, as was shown in research conducted by the Army[28,29] and Navy.[30] Similar to a process used for odor control in industrial applications, it involves spraying water droplets of about 100 to 200 micron diameter into the enclosure. The droplets, which present a large total surface area, absorb the vapor and carry it from the air as they slowly settle. The benefit of these two effects has not been quantified for an application such as sheltering in place.

3.3.1.5 **Potential Measures Not Included in Current Instructions.**

A household vacuum cleaner has been tested as an expedient filter unit to remove airborne particles when sheltering against radiological hazards.[9] Filtering chemical vapors requires an adsorption medium not usually found in households; however, indoor air purifiers that contain a carbon filter medium in addition to a high efficiency particulate air (HEPA) filter are now becoming widely available to consumers. These do not have the sorptive capacity or efficiency of standard carbon filters used in protective equipment, but they offer potential for significantly increasing the protection provided by a safe room in sheltering in place. These are recirculation type units; they filter the air within an enclosure and cannot be applied to establish a pressurized shelter. Similarly, furnace filters that contain a carbon filter medium are now available to consumers. These provide the capability to scavenge chemical vapors when the central HVAC fan is operating. Because of the adverse effects of HVAC operation during sheltering, however, carbon furnace filters should be considered for use in purging the building only after the hazardous plume has passed.

4. TESTS OF EXPEDIENT SEALING MEASURES

4.1 Objective.

The objective of the testing was to determine the effectiveness of expedient sealing measures in reducing the rate and the variability of air exchange of a room selected for sheltering in place.

4.2 Scope and Limitations

A series of 36 experiments was conducted on 10 residential buildings (constructed between 1925 and 1952) and two mobile offices (trailers) at Aberdeen Proving Ground, MD from 19 July through 19 October 1995 to evaluate two expedient sealing methods:

- **Method 1**: Specified in several published procedures, this method involves placing a wet, rolled towel at the base of the door leading into the room and placing duct tape over the HVAC vent and/or exhaust fan inlet (if one or both is present), and taping the electrical outlets.

- **Method 2**: Specified in the NICS videotape, this method involves placing duct tape around the perimeter of the door, taping a plastic sheet over the window, and performing the three steps of Method 1.

The 12 buildings, listed below, were selected for testing based upon their availability and type of construction. Further description and photographs of each are provided in Appendix B.

- Three-bedroom brick Cape Cod, partial basement, built in 1933 (No. 3034)
- Three bedroom brick Cape Cod, partial basement, built in 1933 (No. 3069)
- Four-bedroom stone Cape Cod, full basement, built in 1934 (No. 105)
- Five-bedroom stone Cape Cod, full basement, built in 1935 (No. 54)
- Six-bedroom frame two-story house, full basement, built in 1925 (No. 1222)
- Five-bedroom frame two-story house, full basement, built in 1927 (No. 1236)
- Mobile home (office), double-wide, 24 ft wide, 65 ft long (No. E4587)
- Mobile home (office),12 ft wide, 55 ft long (no. T5354)
- Two-story brick rowhome, three-bedroom, full basement, built 1952 (1330G)
- Two-story brick rowhome, three-bedroom with full basement, end of group, built in 1952 (No. 1330H)
- Two-story brick four-bedroom apartment with separate basement and an apartment beneath, built in 1952 (No. 1342B)
- Two-story brick four-bedroom apartment with separate basement and an apartment beneath, built in 1952 (No. 1345A)

Except for the two mobile homes, all contained replacement double-hung, double-pane windows. Some, but not all, had storm windows as well. Seven of the 10 houses had fireplaces (all fireplace dampers were closed when tested). Only two houses and the two mobile offices had central HVAC. All others had hot water heating systems. There were no window air conditioners in any of the houses. Furniture was present in only one of the buildings, the mobile office No. E4587.

Conditions of the buildings during the testing were those that would exist in sheltering in place: no HVAC systems were in operation. All doors and windows were closed tightly by normal means. There was no occupant activity (each building was unoccupied for the duration of the experiment). No actions were taken other than those that occupants would be expected to take in a sheltering emergency. Only the steps of Method 1 or Method 2 were applied; no attempt was made to block or modify other sources of leakage. When only a single electrical outlet was present in a safe room, no tape was placed over the outlet as it was used as a power source for the instruments and fan. When tape was applied around the door to the safe room, it was of necessity applied to the outside of the door. The wet towel was also placed on the outside of the door in the same manner as it would be applied on the inside of the safe room.

Two types of rooms were selected as the sheltering safe room in each house: bathrooms (with and without windows) and large walk-in closets. Twenty-three different rooms were tested: 14 had windows (one each) and 22 of the 23 had an outside wall. Seventeen were located on the second (upper) floor and six, including those in mobile homes, were located on the ground floor. Table 4 provides a description of safe rooms tested, which were of three general types: bathroom with window, windowless bathroom, or walk-in closet.

4.3 Technical Approach.

The objective of the testing was to measure the natural rate of air exchange between the expediently sealed safe room and the outdoors--to include the effects of both the closed house and the closed room within it--and to measure concurrently the air exchange rate of the whole house. By doing this, the benefit of sealing the safe room could be determined by comparing the air exchange rate of the sealed room with that of the whole house. In taking the two measurements concurrently, the effects of temporal variations in air exchange rate, caused by changes in wind and inside-outside temperature differences, were minimized.

The approach was to employ the tracer gas dilution method using sulfur hexafluoride (SF_6) as the tracer. This method involves three steps: releasing the gas in the building, mixing it well, and measuring its change in concentration over time. To view this method from another perspective, the fresh air outside simulates the hazardous cloud (of a constant concentration), and the SF_6 laden air inside simulates the clean air that is normally within the building. The concentration change that occurs over time is due to the infiltration of fresh air and the exfiltration of SF_6. The more rapid the change, the higher the rate of air exchange. In this testing, the SF_6 was released not only in the sealed room but also throughout the living space of whole house. The tracer was not released in the attics, each of which had gable vents, because the relatively high air exchange rate between the attic and the environment was judged to produce only a minor effect--a slight increase in the tracer dilution rate of second story safe rooms. A uniform initial concentration was achieved in each area of the house by the simultaneous, controlled release of the SF_6 in each area, based upon real-time SF_6 concentration readings in each area.

Thorough mixing is a critical to this method, which is based upon the assumption that the interior of the building is a single, uniformly mixed space. Mixing was achieved by placing fans in each room and by monitoring the SF_6 concentrations continuously over long periods to ensure that a uniform concentration had been achieved before measurements were taken for analysis. The standard technique of operating the central

blower of the HVAC for mixing could not be applied here because operating the blower increases infiltration rate and does not represent sheltering conditions.

Table 4. Description of Safe Rooms Tested

House Number	Type of Safe Room	Number of Windows	Number of Outside Walls	Type Vents	Location
54	Bathroom	1	1	None	First floor
	Bathroom	1	1	None	Second floor
	Walk-in closet	0	1	None	Second floor
105	Bathroom	1	1	None	First floor
	Bathroom	1	1	None	Second floor
1236	Bathroom*	1	1	Vent fan	Second floor
	Bathroom	1	1	Vent fan	Second floor
1222	Bathroom	1	1	None	Second floor
	Walk-in closet	0	2	None	Second floor
1330G	Bathroom	1	1	HVAC	Second floor
1330H	Bathroom	1	1	HVAC	Second floor
1342B	Bathroom	1	1	None	Second floor
	Bathroom	0	1	Vent fan	Second floor
	Walk-in closet	0	1	None	Second floor
1345A	Bathroom	0	1	Vent fan	Second floor
	Bathroom	1	1	None	Second floor
	Walk-in closet	0	1	None	Second floor
3069	Bathroom	0	0	Vent fan	Second floor
	Bathroom	1	1	Vent fan	First floor
3034	Bathroom	0	0	Vent fan	Second floor
	Bathroom	1	1	Vent fan	First floor
E4587	Bathroom	1	1	HVAC	--
T5354	Bathroom	0	1	None	--

* One bathroom of building 1236 had two doors.

The Miniature Infra-Red Analyzer (MIRAN®), manufactured by Foxboro Co. Inc., was selected for use in measuring the SF_6 concentrations because of its capability for continuous, real-time concentration measurements. Readings from the MIRAN® were recorded on a data acquisition system which was located in a mobile laboratory (a High Mobility Multipurpose Wheeled Vehicle, HMMWV) adjacent to the building being tested. The MIRAN® was calibrated to detect concentrations as low as 500 parts per billion by using three standard concentrations of span gases. Calibration data are shown in Appendix C.

The concentration data from each MIRAN® were recorded automatically, and the natural log of the concentration was plotted versus time. The slope of this line equals the number of air changes per hour. Each experiment lasted 16 to 25 hours from the time the gas was released until the concentration measurements were terminated. During this period, the building remained closed and unoccupied. Only one of the 12 buildings, trailer E4587, had furnishings.

One limitation of this approach was that the inside-to-outside temperature differences were less than they would be normally with HVAC systems in use during summer or winter. This was due to the absence of ventilation and air conditioning while the house was closed for long periods. In these tests, this difference ranged from 1.5° to 18.7°F approximating those that would occur in spring or fall. With HVAC systems in use in winter or summer, a difference in the range of 20 to 40°F would be typical.

4.4 Test Equipment and Procedures.

A detailed description of the test equipment and procedures is provided in Appendix C. Weather conditions during each of the trials are shown in Appendix D.

4.5 Test Results and Discussion.

Results of the 36 experiments are summarized in Tables 5 and 6 and presented in detail in Appendix E. A typical graph, one of the concentration decay in the four locations in Bldg 1342B, is shown in Figure 1. In this example, the steeper slope of the two lines for the whole house concentrations indicate that the air exchange rate of the whole house was greater than that of the two safe rooms tested, a sealed bathroom and a sealed closet. The air exchange rate is equal to the slope of the natural log of the concentration versus time.

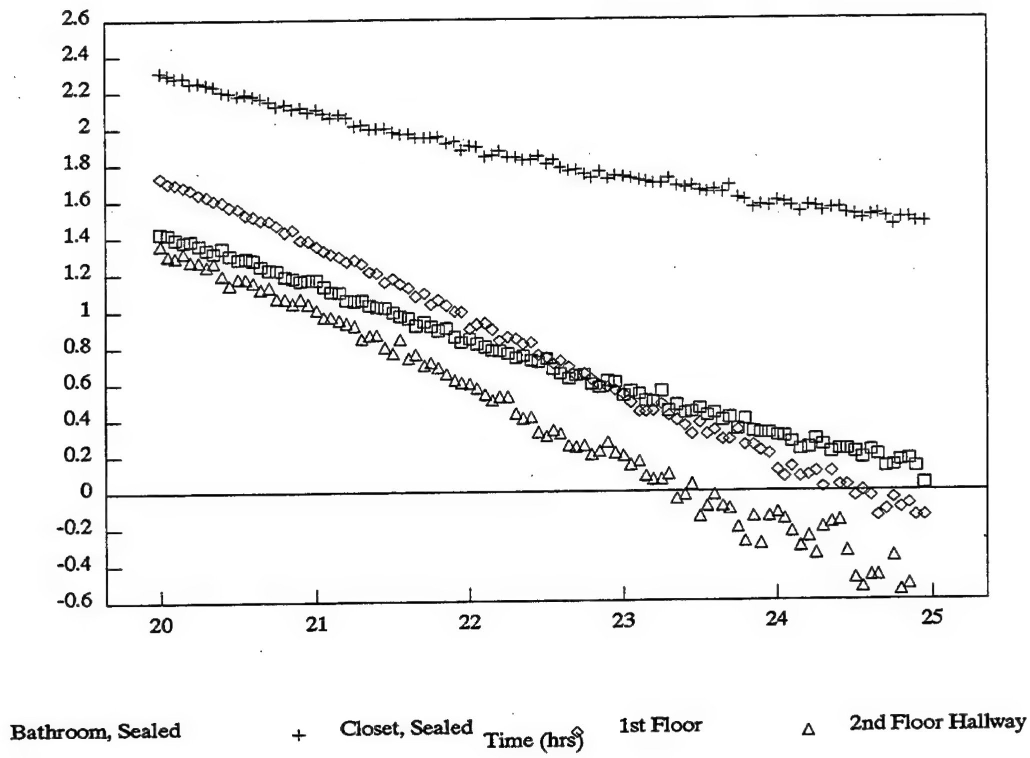

Figure 1. Graph of Concentrations in Four Areas of Bldg 1342B, taken 20 to 25 Hours After the Release of SF_6 on 31 July 1995.

The air exchange rates of both the safe rooms and whole house were found to be log normally distributed, based upon log normal probability plots of the data.[31] Table 5 lists the geometric means and standard deviations calculated for each of the three levels of expedient sealing measures applied to bathrooms containing windows. When no sealing measures were applied, the mean air exchange rate of a bathroom containing a window was 7.8% less than the mean for the whole house, but the exchange rate of the bathroom was greater than or equal to that of the whole house in nine of the 15 trials.

Placing a wet towel at the base of the door and taping vents (Method 1) resulted in a mean reduction of 16.5%, and in only two of the 15 measurements was the exchange rate of the room higher than that of the whole house.

When the more extensive measures of Method 2 were applied (taping around the door and taping plastic sheet over the window), the difference increased to 34.3%. This improvement, consistent with the results obtained in windowless bathrooms, illustrates the significance of leakage associated with windows. As Table 6 shows, when the wet towel was placed at the door and vent was taped in a windowless bathroom, the difference in air exchange rates was approximately the same, 30.3%. The benefit of selecting a room without windows can also be seen by examining the mean values for windowless rooms (Table 6) when no sealing measures are applied: For a walk-in closet with no vents, the mean air exchange rate was 29.4% lower than that of the whole house. For a windowless bathroom with vent, the mean was 22.2% lower than that of the whole house.

Table 5. Results for Bathrooms with Windows

House No./Type	Date	Air exchange rate (ACH) of whole house	Air exchange rate (ACH) of safe room	Reduction: safe room/ whole house
No Sealing Measures Applied to the Closed Bathroom				
54 downstairs: 2-story frame*	8 Sep	0.213	0.150	30%
54 upstairs: 2-story frame*	8 Sep	0.210	0.203	3%
54 downstairs: 2-story frame*	12 Sep	0.245	0.249	increase
54 downstairs: 2-story frame*	13 Sep	0.199	0.172	14%
105 downstairs: 2-story frame*	30 Aug	0.413	0.260	37%
105 upstairs: 2-story frame*	30 Aug	0.273	0.328	increase
1330G upstairs: rowhouse	19 Jul	0.190	0.276	increase
1222 upstairs: 2-story frame*	18 Aug	0.673	0.682	increase
1236 upstairs: 2-story frame	16 Aug	0.166**	0.174	increase
1236 upstairs: 2-story frame	16 Aug	0.166**	0.165	--
1345 upstairs: 2-story apartment*	5 Aug	0.827	0.861	increase
3034 downstairs: 2-story stone	11 Aug	0.364	0.384	increase
3069 downstairs: 2-story stone	8 Aug	0.318	0.316	--
1342 upstairs: 2-story apartment*	28 Jul	0.191	0.114	40%
E4587 double-wide mobile home	6 Oct	0.459	0.443	3%
Geometric mean:		*0.294*	*0.271*	*7.8%*
Geometric std deviation:		*0.203*	*0.237*	
Wet Towel on Door and Tape over Vent (if present) -- Method 1				
54 downstairs: 2-story frame	11 Sep	0.241	0.166	31%
54 upstairs: 2-story frame	11 Sep	0.237	0.194	18%
105 downstairs: 2-story frame	31 Aug	0.231	0.210	9%
105 upstairs: 2-story frame	31 Aug	0.250	0.212	15%
105 downstairs: 2-story frame	5 Sep	0.364	0.295	19%
105 upstairs: 2-story frame	5 Sep	0.368	0.323	12%
1330H upstairs: Rowhouse	25 Jul	0.180	0.210	increase
1330G upstairs: Rowhouse	21 Jul	0.177	0.192	increase
1222 upstairs: 2-story frame	19 Aug	0.581	0.386	34%
1236 upstairs: 2-story frame	17 Aug	0.167	0.162	3%
3034 downstairs: 2-story stone	14 Aug	0.329	0.288	12%
3069 downstairs: 2-story stone	9 Aug	0.203	0.188	7%
1342 upstairs: 2-story apartment	29 Jul	0.366	0.193	46%
E4587 double-wide mobile home	8 Oct	0.479	0.357	25%
Geometric mean:		*0.278*	*0.232*	*16.5%*
Geometric std deviation:		*0.162*	*0.120*	
Tape Around Door, Plastic Sheet on Window, Towel on Door, Tape on Vent -- Method 2				
54 downstairs: 2-story frame	9 Sep	0.230	0.120	48%
54 upstairs: 2-story frame	9 Sep	0.229	0.171	25%
105 downstairs: 2-story frame	6 Sep	0.376	0.295	22%
105 upstairs: 2-story frame	6 Sep	0.395	0.310	22%
E4587 double-wide mobile home	7 Oct	0.462	0.236	49%
Geometric mean:		*0.324*	*0.213*	*34.3%*
Geometric std deviation:		*0.127*	*0.155*	

* This room had no vents, either for a central HVAC or for an exhaust fan.

** These duplicates represent only a single measurement; only one was used to calculate the mean.

Table 6. Results for Windowless Bathrooms and Walk-in Closets

House No. and Type	Date	Air exchange rate (ACH) of whole house	Air exchange rate (ACH) of safe room	Reduction: safe room/ whole house
Windowless Bathroom: No Sealing Measures Applied to Closed Room				
1345 upstairs: 2-story apartment	2 Aug	0.456	0.415	9%
1345 upstairs: 2-story apartment	5 Aug	0.827	0.818	--
3034 upstairs: 2-story stone	11 Aug	0.368	0.347	6%
3069 upstairs: 2-story stone	8 Aug	0.317	0.318	--
1342 upstairs: 2-story apartment	26 Jul	0.296	0.200	32%
1342 upstairs: 2-story apartment	28 Jul	0.191	0.116	39%
1342 upstairs: 2-story apartment	1 Aug	0.240	0.109	55%
T5354 mobile home*	17 Oct	0.582	0.487	17%
Geometric mean:		*0.369*	*0.287*	*22.2%*
Geometric std deviation:		*0.194*	*0.285*	
Windowless Bathroom: Towel on Door, Tape over Vent (if present)				
1345 upstairs: 2-story apartment	3 Aug	0.428	0.226	47%
3034 upstairs: 2-story stone	14 Aug	0.352	0.308	12%
3069 upstairs: 2-story stone	9 Aug	0.211	0.149	29%
1342 upstairs: 2-story apartment	27 Jul	0.377	0.235	38%
1342 upstairs: 2-story apartment	29 Jul	0.366	0.171	52%
1342 upstairs: 2-story apartment	31 Jul	0.389	0.245	37%
T5354 mobile home*	18 Oct	0.541	0.458	15%
Geometric mean:		*0.327*	*0.228*	*30.3%*
Geometric std deviation:		*0.130*	*0.185*	
Windowless Bathroom: Tape around Door, Towel on Door, Tape over Vent (if present)				
T5354 mobile home*	19 Oct	0.343	0.148	57%
Walk-in Closet: No Sealing Measures Applied				
54 upstairs: 2-story frame*	12 Sep	0.266	0.159	40%
1222 upstairs: 2-story frame*	18 Aug	0.673	0.582	13%
1345 upstairs: 2-story apartment*	2 Aug	0.456	0.365	20%
1342 upstairs: 2-story apartment*	26 Jul	0.296	0.176	41%
Geometric mean:		*0.394*	*0.278*	*29.4%*
Geometric std deviation:		*0.160*	*0.232*	
Walk-in Closet: Wet Towel on Door and Tape over Vent (if present)				
1222 upstairs: 2-story frame*	19 Aug	0.581	0.460	21%
1345 upstairs: 2-story apartment*	3 Aug	0.428	0.259	39%
1342 upstairs: 2-story apartment*	27 Jul	0.377	0.371	2%
1342 upstairs: 2-story apartment*	31 Jul	0.389	0.176	45%
Geometric mean:		*0.437*	*0.297*	*32.0%*
Geometric std deviation:		*0.074*	*0.159*	
Walk-in Closet: Tape around Door, Towel on Door, Tape over Vent (if present)				
54 upstairs: 2-story frame*	13 Sep	0.210	0.149	29%

* This room had no vents, either for a central HVAC or for an exhaust fan.

Table 7 provides a comparison of the mean air exchange rates for the various combinations of sealing method and room type. It is apparent that greater protection is obtained when the window is eliminated as a leakage path. The results indicate too that without expedient sealing measures, there is little or no advantage to sheltering in a bathroom that contains a window, even though a bathroom typically has just one window.

Table 7. Comparison of Reductions in Mean Air Exchange Rates Achieved with the Two Sealing Methods and Three Types of Safe Rooms

Bathroom with window	
No sealing measures (n=15)	7.8%
Tape over vent, and wet towel on door (n=14)	16.5%
Tape on door and vent, plastic sheet on window, towel at base of door (n=5)	34.3%
Windowless bathroom (with exhaust fan)	
No sealing measures (n=8)	22.2%
Tape over vent, and wet towel at base of door (n=7)	30.3%
Walk-in Closet (without vents)	
No sealing measures (n=4)	29.4%
Wet towel at base of door (n=4)	32.0%

The largest reduction in air exchange rate measured in the 36 experiments was 57% in a windowless bathroom in a mobile home with tape applied around the bathroom door. A reduction of 55% was measured in a windowless bathroom of a two-story apartment (building 1342). Six experiments were run on this particular bathroom. Reductions of 32, 39, and 55% were measured in three of the experiments without any sealing measures, and 37, 38, and 52% in three with the vent taped and a wet towel placed at the base of the door.

Variability was greater in other cases. In two experiments in which Method 1 sealing measures were applied to a walk-in closet in building 1345, the measured reduction was 2% on 27 July and 45% on 31 July. The large difference appeared to be the result of weather changes: wind gusts up to 29 mi/hr were recorded on 27 July; winds were very light on 31 July.

Overall, the variability in air exchange rate was greater among the safe rooms than among the houses, as seen from the standard deviations listed in Tables 5 and 6. This may be due to inconsistent or inadequate sealing methods and/or to leakage paths not addressed by the expedient measures (such as the sole plate, a major leakage path in most houses). This indicates that a combination of enhanced and expedient sheltering measures applied to a selected room would likely increase the level of protection further.

Among the 36 experiments, the whole house air exchange rates ranged from 0.163 to 0.855 with means of 0.295 upstairs and 0.313 downstairs. The mean of six measurements made on the two mobile homes was 0.471. By comparison, the air exchange rates measured in 11 experiments on windowless bathrooms sealed by Method 1 ranged from 0.149 to 0.460 with a mean of 0.260.

To illustrate the protection that would be achieved with the measured values of air exchange rate, protection factors were calculated using the equation in Section 3.2.1.1. These values were calculated for the high, low, and mean rates at two selected exposure durations and with the assumption that occupants would vacate the building as soon as the cloud passes. These are shown in Table 8. In the weather conditions that existed during the tests, the protection factors would have ranged from 15 to 68 for normal sheltering against a 10-minute hazardous exposure and from 3 to 13 against a 1-hour exposure. With the best expedient room sealing measures, the protection factors improved to a range of 39 to 101 for 10-minute exposure and 7 to 17 for 1-hour exposure. These calculations assume perfect implementation and neglect any filtering effect.

Table 8. Illustration of Protection Factors in the 12 Buildings Tested, Based upon High, Low, and Mean Air Exchange Rates and upon Assumption of Occupants' Immediate Exiting.

For a hazardous exposure of 10 minutes duration	high	mean	low
Normal sheltering[a] downstairs (n=13)	68	39	15
Normal sheltering upstairs (n=29)	67	40	15
Normal sheltering in the two mobile homes (n=6)	35	26	21
Expedient sheltering[b], Method 1 in bathroom with window (n=14)	75	52	32
Expedient sheltering, Method 1 in windowless room[c] (n=11)	91	44	26
Expedient sheltering, Method 2 in bathroom with window (n=5)	101	57	39
Expedient sheltering, Method 2 in windowless room (n=2)	81	81	82
For a hazardous exposure of one hour duration	high	mean	low
Normal sheltering downstairs	13	7	3
Normal sheltering upstairs	13	8	3
Normal sheltering in the two mobile homes	7	5	4
Expedient sheltering, Method 1 in bathroom with window	13	9	4
Expedient sheltering, Method 1 in windowless room	14	8	6
Expedient sheltering, Method 2 in bathroom with window	17	10	7
Expedient sheltering, Method 2 in windowless room	14	14	14

a. The protection factor for normal sheltering is calculated using the whole house air exchange rate measured upstairs or downstairs.

b. The sample for expedient sheltering includes both mobile homes and two story houses.

c. Windowless rooms are both bathrooms and walk-in closets.

5. SUMMARY AND CONCLUSIONS

Several studies have shown that sheltering in place can be an effective means of protecting the public against transient chemical hazards. Sheltering has been adopted by several U.S. communities as a protective action in combination with, or as an alternative to, evacuation. Its effectiveness is implied by its successful application in actual emergencies. Its principal advantage is that it can be implemented more rapidly than evacuation.

The principal disadvantage of sheltering in place is that the protection it affords is highly variable--sensitive to the duration of the hazardous plume, to variability in the air exchange rate of buildings in which the shelter is sought, and to the timing of implementation, particularly with regard to vacating the shelter after the hazardous plume has passed.

Procedures for sheltering in place have been published in the U.S. by at least 10 organizations or communities in which hazardous industrial chemicals are stored or processed. In most cases, the procedures specify what is defined as normal sheltering, that is, no expedient sealing measures are specified. These published procedures were evaluated in this study, and a set of recommended procedures were written for potential application under the CSEPP. These procedures appear in Appendix F.

To determine the effectiveness of two types of expedient sealing measures, tracer gas tests were conducted on 12 buildings at Aberdeen Proving Ground, MD. Although these buildings are not representative of the broad range of buildings that could be used for sheltering under the CSEPP, the results demonstrate that the expedient sealing measures can reduce air exchange rates substantially and therefore increase the protection provided by sheltering in place.

In applying the simpler Method 1 (placing a wet, rolled towel at the base of the door and taping any vents) to a bathroom with a window produced a 16.5% mean reduction in air exchange rate. Applied to a windowless bathroom or walk-in closet, this method yielded a mean reduction of 30 to 32%.

Applying the more extensive Method 2--taping around the door and taping a sheet of plastic over the window--to a bathroom containing a window produced a mean reduction of 34.3%.

For the 12 houses tested and the specific weather conditions that existed during the tests, protection factors would have ranged from 15 to 68 for normal sheltering against a 10-minute hazardous exposure. Against a 1-hour exposure, they would have ranged from 3 to 13.

With the best expedient room sealing measures, the protection factors would have increased to a range of 39 to 101 for 10-minute exposure and to 7 to 17 for 1-hour exposure. This illustration assumes perfect implementation and neglects any filtering effect.

Although expedient sealing measures on selected rooms produced lower mean air exchange rates, there was greater variability in the rates among the sealed rooms than among the houses. This indicates that further gains in protection can be achieved by finding better sealing techniques and/or sealing other leakage paths such as the sole plate in the selected safe room.

There is also strong potential for improving protection through the use of a relatively low cost consumer type indoor air purifier (recirculation filter unit) in the selected safe room. Application of such filter units containing charcoal filter elements should be further evaluated.

To determine the parameters for safe application under the CSEPP, further study is needed in two areas:

- To develop estimates of the probable duration of an accidental release from a chemical agent demilitarization facility. Sheltering is most effective against hazards of short duration; however, what constitutes an acceptably short exposure varies with a number of factors. The most likely range of exposure duration must be defined to determine the specific applicability of sheltering to the CSEPP.

- To quantify the filtering effect. There are no data available on the rates of absorption of the chemical agents by building materials, rates which are specific to each agent and the material to which it is exposed. Neglecting this effect yields conservative estimates of protection but also results in underestimating the period needed to purge the building after exposure.

6. RECOMMENDATIONS

Develop estimates of probable duration of accidental releases that are possible from the chemical weapons storage and demilitarization facilities.

Acquire data on absorption and desorption rates of the chemical agents on materials typically found in buildings and perform analyses to estimate the effect of absorption in increasing the protection and in extending the purging period after the hazard has passed.

Test and evaluate the use a consumer type indoor air purifier (recirculation filter containing carbon filter elements) to increase the protection afforded by sheltering in a selected room.

Evaluate the combination of both enhanced sheltering measures (permanent sealing of areas such as the sole plate) and expedient measures to reduce the air exchange rate of a selected safe room.

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APPENDIX A
PUBLISHED PROCEDURES FOR SHELTERING IN PLACE

AMERICAN RED CROSS

Shelter in Place: One of the basic instructions you may be given in a chemical emergency is to shelter-in-place. This is a precaution aimed to keep you and your family safe while remaining in your home. If you are told to shelter-in-place, take your children and pets indoors immediately.

While gathering your family, you can provide a minimal amount of protection to your breathing by covering your mouth and nose with a damp cloth.

- Close all windows in your home.
- Turn off all fans, heating, and air conditioning systems.
- Close the fireplace damper.
- Go to an above ground room (not the basement) with fewest windows and doors.
- Take your Family Disaster Supplies Kit with you.
- Wet some towels and jam them in the crack under the doors. Tape around doors, windows, exhaust fans or vents. Use the plastic garbage bags to cover windows, outlets, and heat registers.
- If you are told there is danger of explosion, close the window shades, blinds, or curtains. To avoid injury, stay away from the windows.
- Stay in the room and listen to your radio until you are told all is safe or you are told to evacuate.

THE CITY OF DEER PARK, TEXAS

Shelter in place steps to follow during a chemical emergency in deer park:

1. When you hear the OUTSIDE WARNING SYSTEM, go inside the nearest home or building and shut the doors and windows.

2. Tune the radio station, 530 AM for emergency instructions.

3. Keep the phone lines open for official use. (Deer Park's computerized telephone notification system will notify citizens in affected areas.)

Additional tips for Sheltering in Place:

- Stay inside unless you are told you can safely leave.
- Turn off heating, cooling, or ventilation systems. Close the fireplace damper.
- If your eyes, nose, or throat become irritated, protect your breathing by covering your mouth with a damp cloth, taking frequent shallow breaths and staying calm.
- If you are in a vehicle, close windows and turn off air systems.

If emergency occurs during school hours, students will be cared for and sheltered in the schools until the emergency is over.

CHARLESTON, KANAWHA COUNTY, WEST VIRGINIA

1. Shelter in place is a proven, effective emergency protective action which is used when there is insufficient time to evacuate in the event of an airborne hazardous material release. In the event of such a release, you may be told to SHELTER IN PLACE rather than to evacuate.

2. Go inside your home or some other building preferably in a room with no or few windows.

3. Stay inside until your radio or television says you can leave safely.

4. Turn off heating or cooling systems, turn off window and other fans, shut your windows and doors, and cover cracks with tape or wet rags.

5. If you are told to protect your breathing, cover your nose and mouth with a handkerchief or other cloth, wet if possible.

6. Keep your pets inside.

7. Listen to the radio or television for further advise.

8. The following is an example of the type of announcement you might hear:

"At (time) today, local authorities reported an industrial accident involving hazardous materials. The accident occurred at (location and time) today. All persons in (names of areas) should remain inside their houses or some other closed building until their radio or television says they can leave safety. If you are in this area, turn off heating and cooling systems and windows or attic fans. Close all windows, doors and vents, and cover cracks with tape or wet rags. Keep your pets inside. Until you can reach a building, cover your nose and mouth with a handkerchief or other cloth. Listen to the radio or television for further advice."

9. As soon as it can be determined that the hazardous condition has passed, local authorities will announce the emergency is over. If the emergency involved a hazardous material cloud, at the "all clear" you will be instructed to open windows and doors, ventilate the building, and go outside.

Note: This information, except for paragraph 8, appeared on the Community Emergency information page of the 1989 Chesapeake and Potomac Telephone Company of West Virginia:

LOUISVILLE/JEFFERSON COUNTY, KENTUCKY

When You Hear the Community Alert Sirens, go indoors - Turn on radio and TV.

If there has been a chemical release:

- Close all windows and doors
- Block out all outside air
- Turn off air conditioner
- Turn off furnace

Approximately 30 minutes after the siren has sounded, turn to 1610 am for special information from the scene.

Don't call 911 unless you have an emergency. Get information from 1610 am and your favorite radio or TV station.

MICHIGAN STATE POLICE

IN-PLACE PROTECTION CHECKLIST:

1. Determine area to be sheltered in-place by readily identifiable boundaries.
2. Activate alert warning devices (sirens).
3. Issue specific instructions to population (through EBS, cable TV).
4. Implement in-place protection, including:

- Stay inside house or building, or go inside immediately.
- Close windows and doors.
- Turn off air conditioners and heating system blowers.
- Close fireplace dampers.
- Gather radio, flashlight, food, water, medicines, duct tape.
- Go to inside leeward area of basement of building and seal cracks and openings to provide extra protection (particularly if inside stay is to be longer than 2 hours).
- Do not use basements if toxic gases are heavier than air.
- Provide protective breathing, if necessary (may be wet towel).

5. Provide special sheltering for transient populations (in campgrounds, marinas, parks)
6. Provide special instructions to special populations (hospitals, nursing homes, etc.).
7. Provide special instructions to group quarters (prisons, jails, senior centers, care centers).
8. Provide special instructions/aid to handicapped (mental and physical).
9. Once conditions have stabilized, monitor and inspect affected areas for safe exit.
10. Issue all-clear.
11. Instruct residents to go outdoors, air out house or building.

BUCKS COUNTY, PENNSYLVANIA

What...
During an accidental release of toxic chemicals or other emergencies where air quality is threatened, In-Place Sheltering keeps you inside a building and out of danger.

In-Place Sheltering simply means staying inside the building you are in, whether it's your home, business, or other facility, or seeking shelter in the nearest available building.

In some instances, In-Place Sheltering is your best defense against accidental release of toxic chemicals. This brochure will explain the simple steps you should take in the event you are directed to seek In-Place Sheltering during an emergency.

When...
It is the responsibility of local authorities to issue orders for In-Place Sheltering during chemical emergencies. You may receive these orders directly from Police or Fire officials, or through a media source, such as the radio or television.

As soon as you are aware that an emergency situation exists in your area, immediately turn on your television or radio for further information.

Local officials will relay emergency action steps to the media on a continual basis until the crisis is over.

Once the order for In-Place Sheltering has been issued, do not leave your home until you receive official notification that the danger has passed. Again, this information will be released to the media, and you may also receive this information directly from the Police or Fire Departments.

Where and How...

In Your Home:
Close and lock all the doors and windows to the outside. (Windows often seal better when locked.)

If possible, bring outdoor pets inside. Turn off all heating systems.

Turn off all air conditioners and switch inlets to the "closed" position. Seal any gaps around window-type air conditioners with tape and plastic sheeting, wax paper, aluminum wrap, or any other suitable material. Turn off all exhaust fans in kitchens, bathrooms, and any other spaces.

Close all fireplace dampers and seal all openings with tape and plastic sheeting, wax paper, aluminum wrap, or other suitable material.

Close as many internal doors as possible in your home or building.

Use tape and plastic food wrapping, wax paper, or aluminum wrap to cover and seal

bathroom exhaust and grilles, range vents, dryer vents, and other openings to the outdoors to the extent possible. Make sure you seal any obvious gaps around external windows and doors.

Close the drapes, curtains, or shades over windows to protect yourself against any possible explosion from the outside. Stay away from external windows to prevent possible injury from flying glass.

If the vapors begin to bother you, hold a wet cloth or handkerchief over your nose and mouth. For a higher degree of protection, go into the bathroom, close the door, and turn on the shower in a strong spray to "wash" the air. Seal any opening to the outside of the bathroom as best you can. Do not worry about running out of air to breath, as this is very unlikely in normal homes and buildings.

In Your Workplace:

In addition to the directions listed In our Home, you should...

Ensure all ventilation systems are set to 100% recirculation so that no outside air is drawn into the structure. Where this is not possible, ventilation systems should be turned off.

Minimize the use of elevators. Elevators tend to "pump" outdoor air in and out of a building as they travel up and down.

CONTRA COSTA COUNTY, CALIFORNIA

Contra Cost County's Health Services Department advises that *shelter-in-place* is the best way to protect yourself in the event of a chemical accident.

- Go inside (take pets with you).

- Close and lock all windows and doors (locking strengthens seal).

- Turn off all ventilation such as heating and air conditioner.

- Turn on the radio or TV for information.

- Stay off the phone unless you have a life threatening emergency (the CAN phone system may call with further instructions).

- Close all fireplace dampers.

- If there are gaps in the windows or doors, seal with tape or wet towels. Larger gaps, bathroom fan grilles, dryer vents, etc. should be sealed with tape and plastic or aluminum foil.

- If you suspect the chemical has entered your house, hold a wet cloth over your nose and mouth.

NATIONAL INSTITUTE FOR CHEMICAL STUDIES

Sheltering-in-Place instructions:

Select a room: find one with few doors/windows. Keep an emergency supply kit with:

Heavy plastic and duct tape
Battery powered radio
Flashlight
First aid kit
A small quantity of non perishable food and drinking water.
Towels

To reduce your exposure to leaked chemicals; to minimize injuries to self and family.

- Move people indoors immediately
- Close and lock all windows and doors.
- Turn off heating or cooling systems, window and attic fans
- Go into one (pre-selected) room,

Contaminated air can enter quickly if there is a delay in preparing the room. To prepare the room:

- Place plastic or duct tape around windows and doors. Use heavy plastic such as drop cloths.
- Tape outlets, tape around door, and place a wet towel at bottom of door.
- Turn on a radio or television and listen for further instructions. When you hear all clear open all windows and doors and go outside immediately.

Attempting to evacuate can in some instances expose you to greater amounts of contaminated air and is not always the safest approach. There are situations where staying put is best.

1. When the exposure is of short duration.
2. When there is not enough time to evacuate.
3. Danger could overtake you if outside.
4. The chemical release has a low heath hazard and not serious enough to evacuate.

OAK RIDGE NATIONAL LABORATORY

EXPEDIENT SHELTER INSTRUCTION CHECKLIST

1. Prepare your dwelling to provide protection.
   a. Go or stay indoors.
   b. Close all exterior doors and windows.
   c. Close all interior doors.
   d. Turn off fans.

2. Select an appropriate room within your dwelling to provide maximum shelter, having at least 10 square feet of floor area per person.

a. Choose a relatively small room with no outside walls on the ground floor.
b. If not available: select a small room with no windows.
c. If not available: select the room with the fewest windows and doors.
d. Avoid rooms with window air conditioners, windows that leak, vents to the outside, and circulation vents whenever possible.
e. Avoid rooms with plumbing fixtures whenever possible.

3. Assemble the necessary materials.

a. Use the expedient shelter kit provided;
b. Verify that its contents are complete;
c. Large towel of at least bath-towel size;
d. Ladder, stool, or chair if necessary.
e. Radio, television, or other communication device;
f. Drinking water and covered container with chlorine bleach for sanitary purposes.

4. Seal a room in the dwelling to provide additional protection.

a. Enter the selected room and close the door.
b. Jam the towel under the door.
c. Seal vents.
d. Seal windows.
e. Check all supplies; replace if necessary.
f. Seal door.
g. Seal plumbing.
h. Seal cabinets
i. Seal electrical fixtures.
j. Check your work; reseal where necessary.

5. Remain in the shelter until notified that the plume has passed.

a. Get as comfortable as possible.
b. Remain calm, relax, and stay immobile.
c. Turn on communication device.
d. Periodically check for airflows in the shelter.
e. Wait for notification of plume passage.

6. Vacate shelter.

a. Don protective clothing.
b. Open all windows and doors.
c. Evacuate.

PONT-DE-CLAIX, FRANCE
(A public information leaflet "What to do in the Case of a Gas Leak if you Live at Pont-de-Claix..." from *UNEP Industry and Environment*, April/May/June, 1988, p. 15-17).

1. Go straight indoors. Buildings serve as a useful screen between yourself and any leaked gas.

2. Close all doors, windows, and if possible, shutters (if they can be closed from the inside). Switch off ventilation, and block all air vents.

3. If possible, wait in a room on the side away from the factory, preferably having a water outlet (bathroom, WC or kitchen). Close all doors to rooms and between rooms.

4. A little gas may seep into the room. If the gas fumes become too powerful, soak a heavy cloth or woollen abundantly in the water and press it against your nose and mouth. Breath slowly through this "filter".

5. If you feel a prickling sensation on the exposed parts of the body (hands or face), wash them abundantly with water.

6. Stay calm and stay indoors. Keep breathing through your cotton or wool "filter". Change it if it starts letting in too much gas.

(When) the "all clear" signal has been confirmed, it is now safe to open your windows.
IN SOME CASES: SIP is the <u>only</u> alternative....

TOOELE COUNTY, UTAH

Two Ways to Escape Chemical Exposure

Chemicals travel the interstate and local rail lines daily. If there is ever a spill, there are two ways to keep yourself safe from the chemical. You can either leave the affected area or protect yourself in place by creating a sealed environment where the hazard cannot reach you.

Emergency planners call these two options "evacuation" and "in-place sheltering." The better or preferred of the two options is evacuation because it removes you from the danger zone. But if there isn't enough time to evacuate, it's a good idea to consider a "shelter in place" protection.

Sheltering in Place

In-Place sheltering means staying inside your home, business, or other permanent building. During an accidental release of toxic chemicals involving hazardous material where air quality may be threatened, in-place sheltering keeps you inside a protected area and out of danger. If emergency authorities recommend sheltering in place, do the following:

Go inside a secure building that can keep you away from the outside air (automobiles are not a wise option because they are not air-tight).

If possible, bring outdoor pets inside. Do not risk your safety for your pets.

Close and lock all outside doors and windows.

Tune to an Emergency Broadcast System station on your radio or television and follow instructions give by emergency authorities.

Move to an above-ground room and remain there until you are told by police, fire, or other emergency officials that it is OK to leave.

Turn off all heating and air conditioning systems or switch the systems to use circulated air only.

Seal off all gaps where the contaminated air could come inside the building with plastic sheeting, plastic wrap, or some other air-tight material.

Cover or close off all fireplace dampers, heat and air conditioning inlets, doors, windows, and cracks.

Do no worry about running out of air to breathe. This is very unlikely to happen in normal sized homes and buildings.

If time does not permit you to seal the entire home, close as many internal doors as possible, move to the most central above ground room in the home and seal that room.

Do not attempt to pick up children from school until directed to do so. School officials have plans to care for school children in emergencies.

Sheltering in Place at Work

If you are at work during a hazardous materials emergency and are asked to shelter in place, do the following:

Ensure that all ventilation systems are set at 100 percent recirculated air or turn them off.

Move to the center, most isolated above ground room and close the doors behind you.

Remember to take a battery powered radio to listen for announcements on the Emergency Broadcast System or a news broadcast.

Be ready to evacuate when it is safe.

Minimize the use of elevators. They tend to "pump" air into and out of buildings while moving up and down.

APPENDIX B
PHOTOS AND SPECIFICATIONS OF BUILDINGS TESTED IN THIS STUDY

Figure B-1. House 54, Front View.

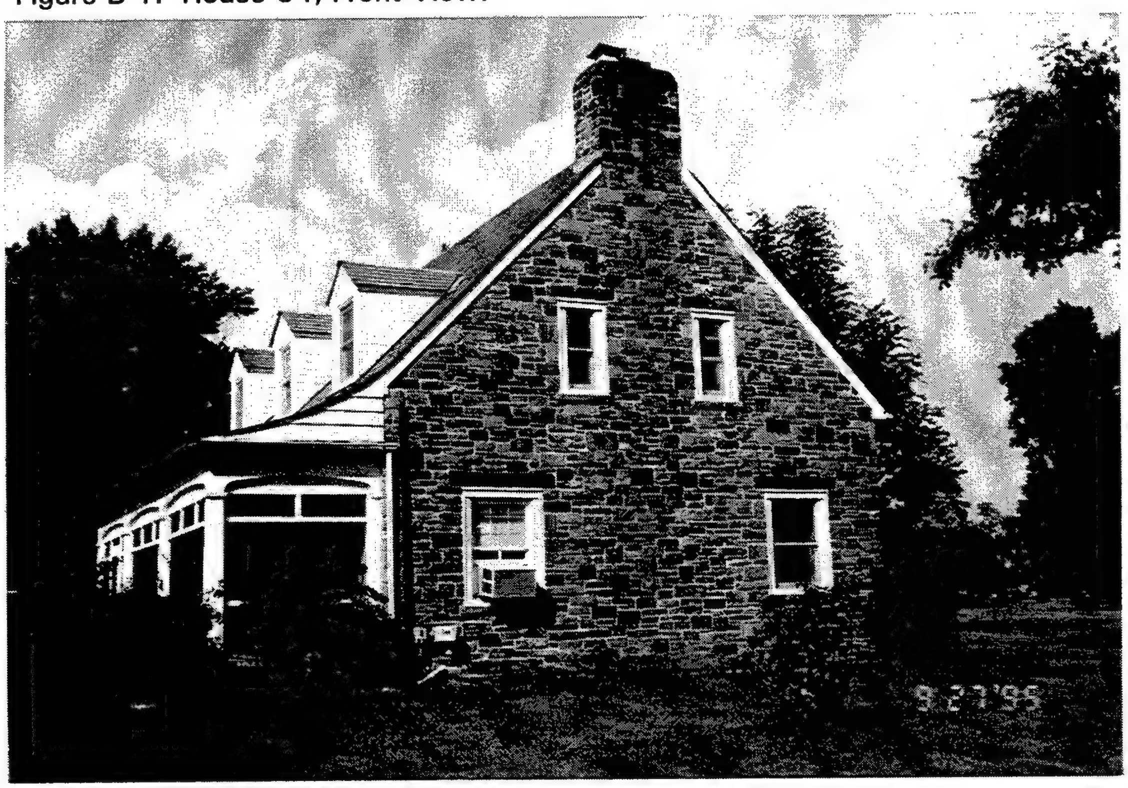

Figure B-2. House 54, Side View

Figure B-3. House 105, Front View

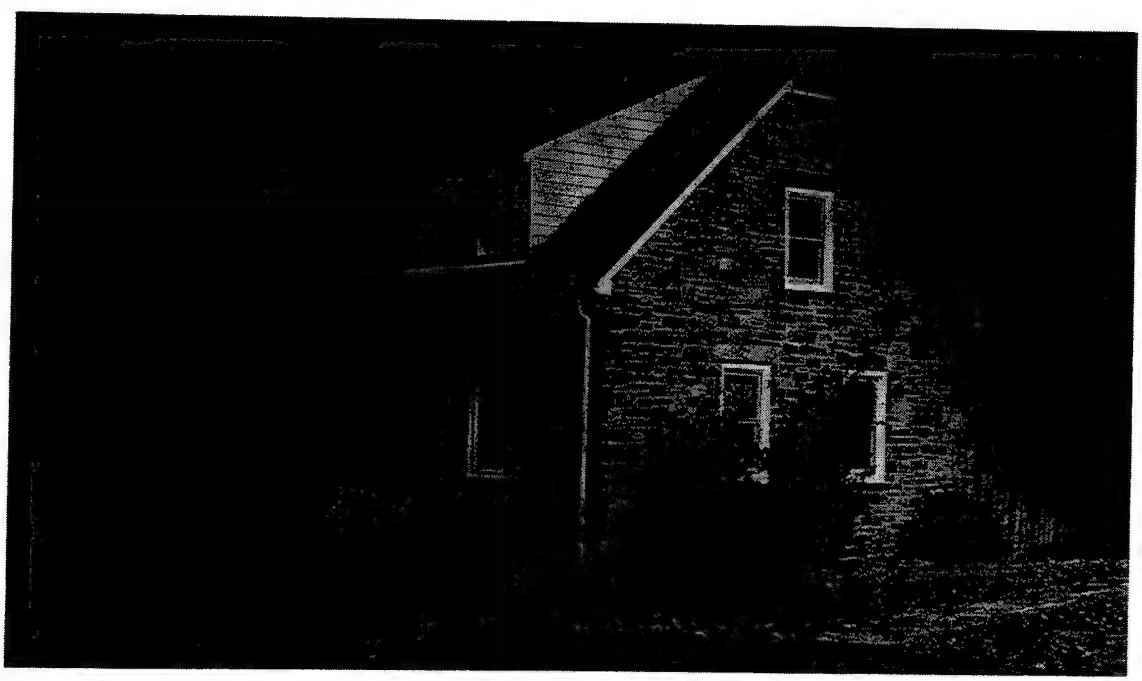

Figure B-4. House 105, Side View

Figure B-5. House 1222, Front View

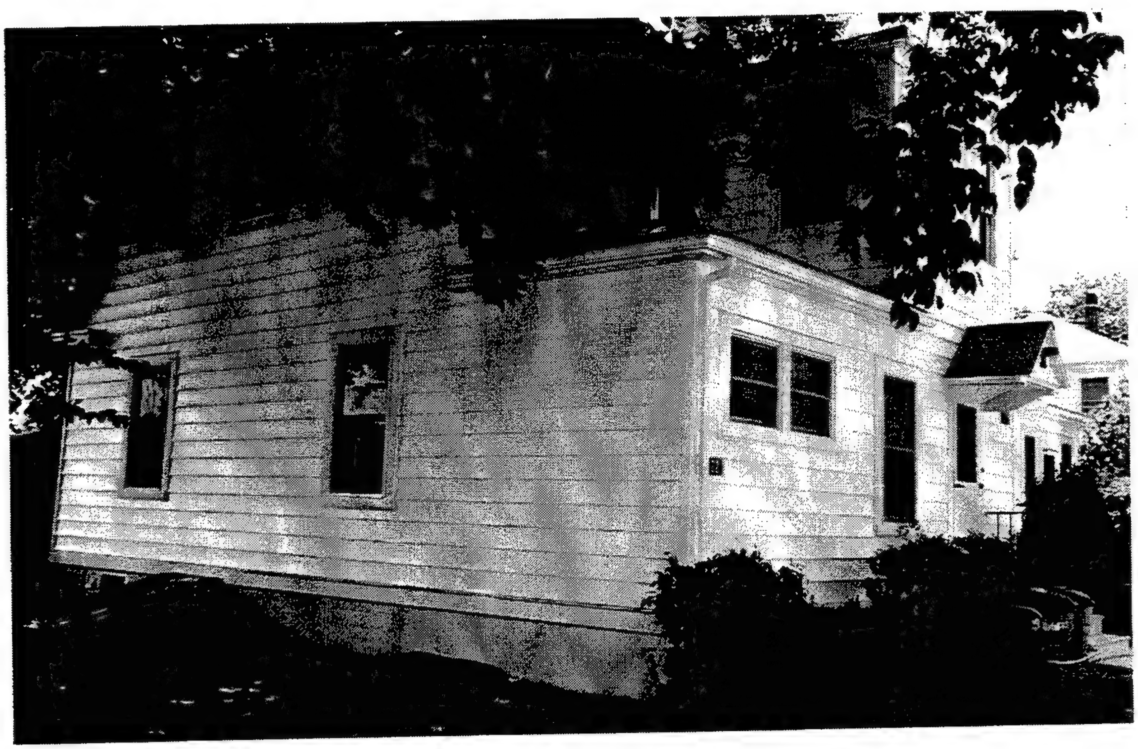

Figure B-6. House 1222, Side View

Figure B-7. House 1236, Front View

Figure B-8. House 1236, Back View

Figure B-9. House 1330G, Front View

Figure B-10. House 1330G, Back View

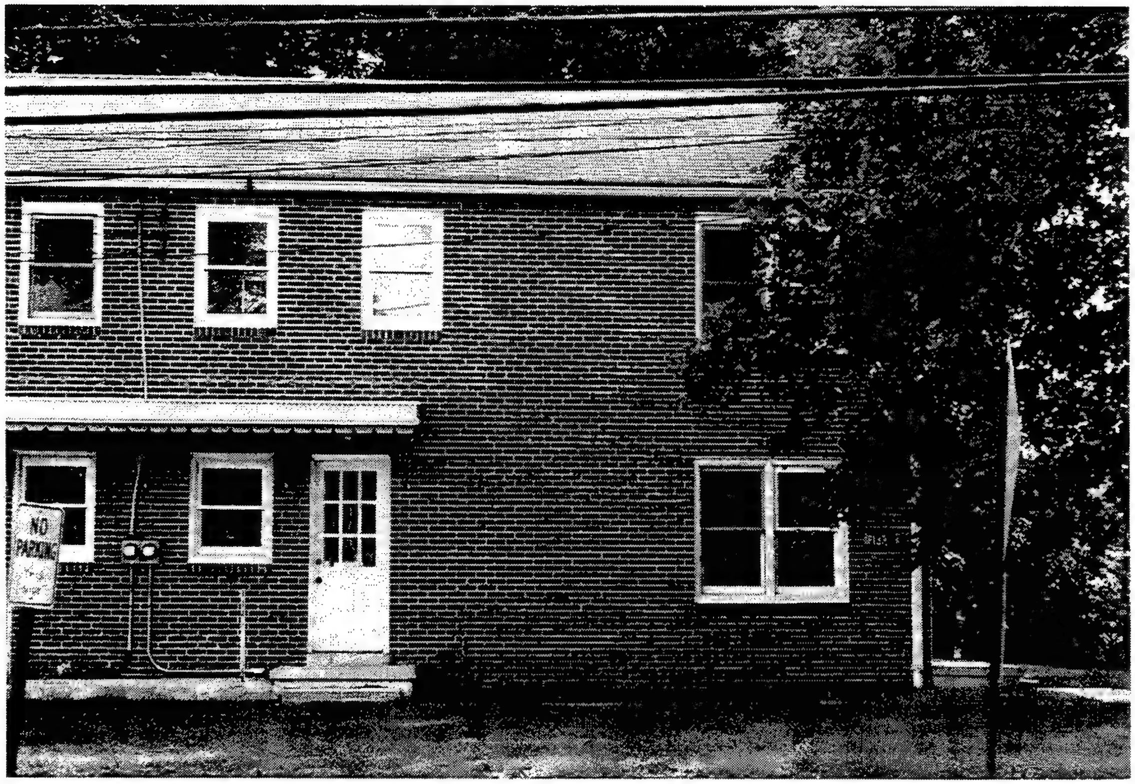

Figure B-11. House 1330H, Front View

Figure B-12. House 1330H, Rear View

Figure B-13. House 1342A, Front View

Figure B-14. House 1342A, Back View

Figure B-15. House 1345B, Front View

Figure B-16. House 1345B, Rear View

Figure B-17. House 3034, Front View

Figure B-18. House 3034, Rear View

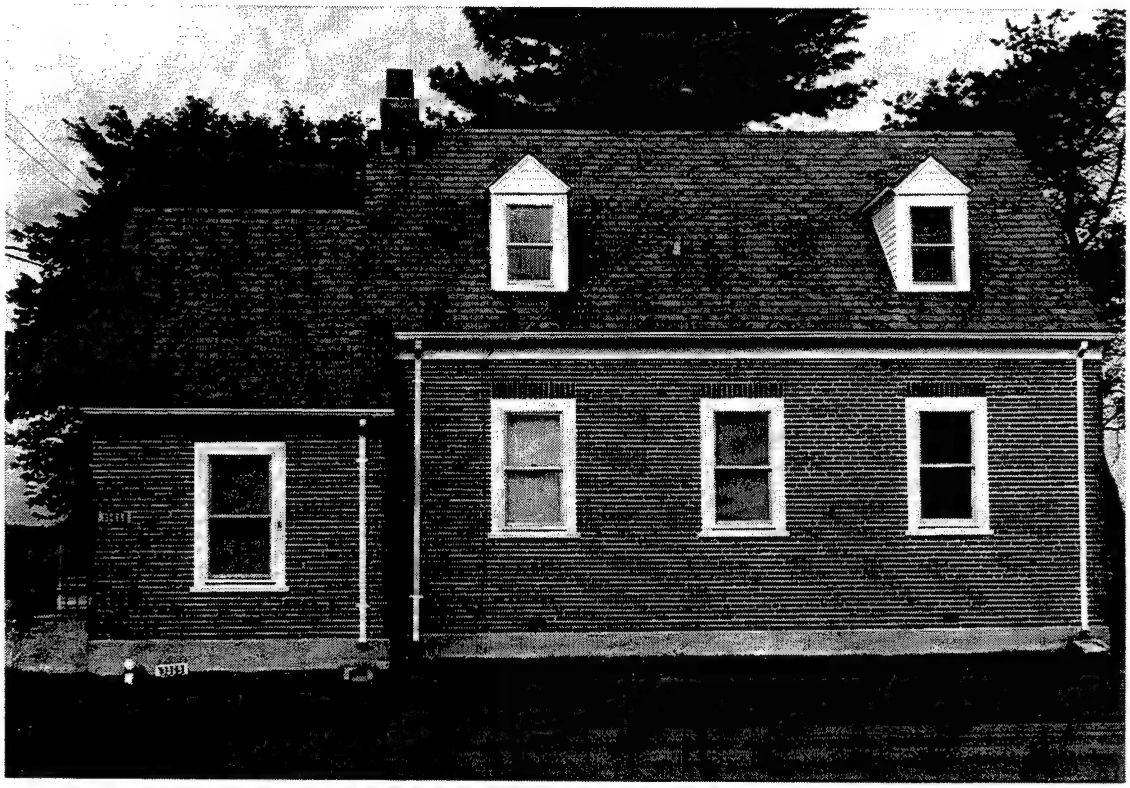

Figure B-19. House 3069, Front View

Figure B-20. House 3069, Side View

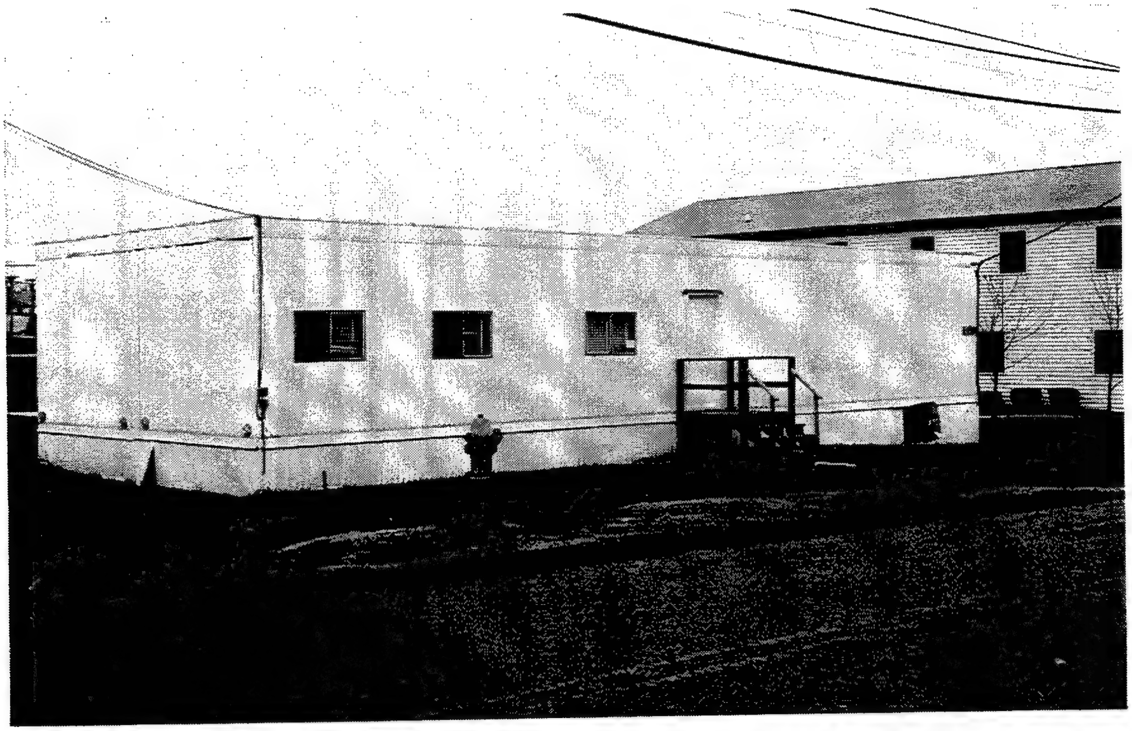

Figure B-21. Trailer 4587, Front View

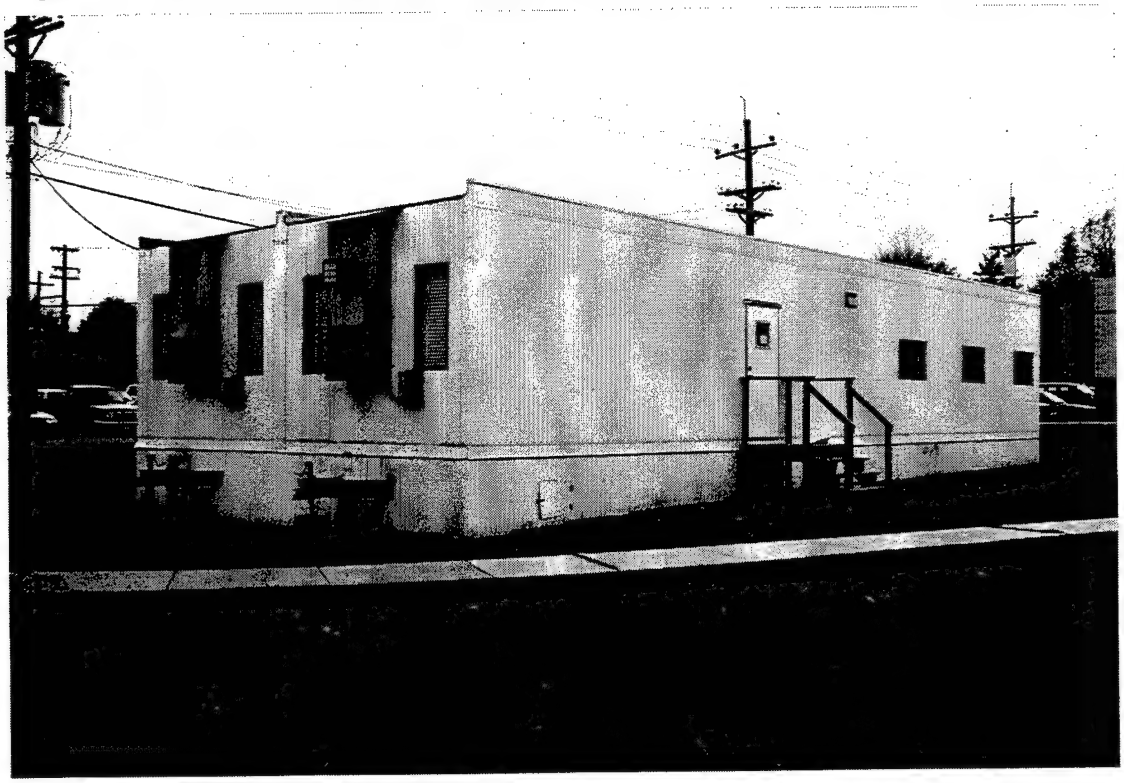

Figure B-22. Trailer 4587, Back View

Figure B-23. Trailer 5354, Front View

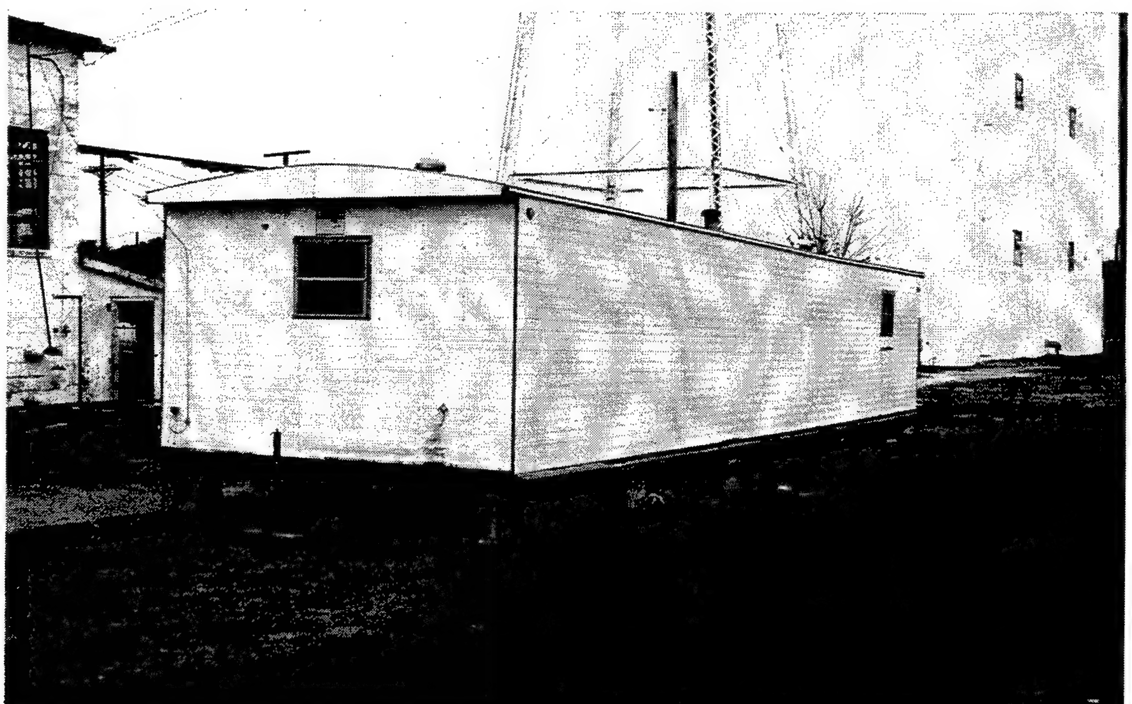

Figure B-24. Trailer 5354, Back View

SPECIFICATIONS OF BUILDINGS TESTED

	1330H	1330G
Type construction	Wood frame/brick	Wood frame/brick
Year of construction	1952	1952
Number of rooms	6	6
Number of bedrooms	3	3
Number of external doors	3	3
Number of windows	21	14
Type windows	Double pane/double hung	Double pane/double hung
Type floor covering	Hardwood	Hardwood
Type heating	Steam radiator	Steam radiator
Type air conditioning	Central Air	Central Air
Number of fireplaces	0	0
Safe room No. 1		
Type room	Bathroom	Bathroom
Dimensions (width, length, ht)	8.4 ft x 4.8 ft x 7.9 ft	8.4 ft x 4.8 ft x 7.9 ft
Number of windows	1	1
Dimensions of window	2.4 ft x 3.2 ft	2.4 ft x 3.2 ft
Exhaust fan	None	None
Diameter, exhaust opening	--	--
Number of electrical outlets	1	1

	1342B	1345B
Type construction	Wood Frame/Brick	Wood Frame/Brick
Year of construction	1952	1952
Number of rooms	10	10
Number of bedrooms	4	4
Number of external doors	3	1
Number of windows	29	21
Type windows	Double pane/double hung	Double pane/double hung
Type floor covering	Hardwood	Hardwood
Type heating	Steam radiator	Steam radiator
Type air conditioning	Central Air	Central Air
Number of fireplaces	0	0
Safe room No. 1		
Type room (closet, etc)	Bathroom	Bathroom
Dimensions (width, length, ht)	5.2 ft x 5.5 ft x 7.7 ft	5.3 ft x 5.5 ft x 7.8 ft
Number of windows	0	0
Dimensions of window	--	--
Exhaust fan	1	1
Diameter, exhaust opening	7.5 in.	8 in.
Number of electrical outlets	1	1
Safe room No. 2		
Type room (closet, etc)	Closet	Closet
Dimensions (width, length, ht)	7.3 ft x 6.5 ft x 7.7 ft	7.3 ft x 6.5 ft x 8 ft
Number of windows	0	0
Dimensions of window	--	--
Exhaust fan	None	None
Diameter, exhaust opening	--	--
Number of electrical outlets	0	0

	1222	1236
Type construction	Wood frame	Wood frame
Year of construction	1925	1927
Number of rooms	13	11
Number of bedrooms	6	5
Number of external doors	4	3
Number of windows	37	38
Type windows	Double pane/double hung	Double pane/double hung
Type floor covering	Hardwood	Hardwood
Type heating	Steam radiator	Steam radiator
Type air conditioning	Central Air	Central Air
Number of fireplaces	1	1
Safe room No. 1		
Type room (closet, etc)	Closet	Bathroom
Dimensions (width, length, ht)	6.6 ft x 3.9 ft x 8.8 ft	6.7 ft x 5.5 ft x 7.8 ft
Number of windows	0	1
Dimensions of window	--	1.7 ft x 2.9 ft
Exhaust fan	None	1
Diameter, exhaust opening	--	6 in.
Number of electrical outlets	0	1
Safe room No. 2		
Type room (closet, etc)	Bathroom	Bathroom
Dimensions (width, length, ht)	5.5 ft x 8.4 ft x 8.8 ft	8.3 ft x 6 ft x 7.9 ft
Number of windows	1	1
Dimensions of window	2.6 ft x 3.3 ft	2.6 ft x 4.3 ft
Exhaust fan	None	1
Diameter, exhaust opening	--	9.7 in.
Number of electrical outlets	1	1

	3034	3069
Type construction	Wood Frame/Brick	Wood Frame/Brick
Year of construction	1933	1933
Number of rooms	10	10
Number of bedrooms	4	4
Number of external doors	2	2
Number of windows	21	21
Type windows	Double pane/double hung	Double pane/double hung
Type floor covering	Hardwood	Hardwood
Type heating	Steam radiator	Steam radiator
Type air conditioning	Central Air	Central Air
Number of fireplaces	1	1
Safe room No. 1		
Type room (closet, etc)	Bathroom	Bathroom
Dimensions (width, length, ht)	8.2 ft x 6.1 ft x 8.7 ft	8 ft x 6.1 ft x 8.6 ft
Number of windows	1	1
Dimensions of window	2.6 ft x 5 ft	2.6 ft x 4.9 ft
Exhaust fan	1	None
Diameter, exhaust opening	4.5 in.	--
Number of electrical outlets	1	1
Safe room No. 2		
Type room (closet, etc)	Bathroom	Bathroom
Dimensions (width, length, ht)	4.8 ft x 5.9 ft x 7.9 ft	4.8 ft x 6 ft x 8 ft
Number of windows	1	0
Dimensions of window	2 ft x 2.8 ft	--
Exhaust fan	1	1
Diameter, exhaust opening	6 in.	4.5 in.
Number of electrical outlets	1	1

	54	105
Type construction	Wood Frame/Stone	Wood Frame/Stone
Year of construction	1935	1934
Number of rooms	10	10
Number of bedrooms	5	4
Number of external doors	2	2
Number of windows	22	22
Type windows	Double pane/double hung	Double pane/double hung
Type floor covering	Hardwood	Hardwood
Type heating	Steam radiator	Steam radiator
Type air conditioning	Central Air	Central Air
Number of fireplaces	1	1
<u>Safe room No. 1</u>		
Type room (closet, etc)	Bathroom	Bathroom
Dimensions (width, length, ht)	7.3 ft x 5.6 ft x 8.8 ft	6.2 ft x 8.3 ft x 8.8 ft
Number of windows	1	1
Dimensions of window	2.5 ft x 3.9 ft	2.6 ft x 5 ft
Exhaust fan	None	None
Diameter, exhaust opening	--	--
Number of electrical outlets	1	1
<u>Safe room No. 2</u>		
Type room (closet, etc)	Bathroom	Bathroom
Dimensions (width, length, ht)	6.9 ft x 5.5 ft x 8 ft	7.4 ft x 6.5 ft x 7.9 ft
Number of windows	1	1
Dimensions of window	1.5 ft x 3.9 ft	1.7 ft x 2.9 ft
Exhaust fan	None	None
Diameter, exhaust opening	--	--
Number of electrical outlets	1	1
<u>Safe room No. 3</u>		
Type room (closet, etc)	Closet	--
Dimensions (width, length, ht)	7.7 ft x 3.5 ft	
Number of windows	0	
Dimensions of window	--	
Exhaust fan	None	
Diameter, exhaust opening	--	
Number of electrical outlets	0	

	T5354	E4587
Type construction	Mobile office (single)	Mobile office double wide
Dimensions (width, length)	12 ft by 44 ft	23½ ft x 60 ft
Number of rooms	4	4
Number of bedrooms	--	--
Number of external doors	2	2
Number of windows	7	10
Type windows	Sliding	Crank
Type floor covering	Linoleum tile	Carpet
Type heating	Central forced air	Central forced air
Type air conditioning	None	Central
Number of fireplaces	None	None
Safe room No. 1		
Type room (closet, etc)	Bathroom	Bathroom
Dimensions (width, length, ht)	4 ft x 8 ft x 7 ft	4.8 ft x 5 ft x 8 ft
Number of windows	0	1
Dimensions of window	--	9 in. x 14 in.
Exhaust fan	0	1
Diameter, exhaust opening	--	8 in.
Number of electrical outlets	1	1

APPENDIX C
DESCRIPTION OF TEST EQUIPMENT AND PROCEDURES

1. MATERIALS AND EQUIPMENT

- Sulfur hexafluoride (SF_6)
- Miniature Infrared Analyzer (MIRAN)® manufactured by Foxboro Co. Inc.,
- Mass flow controllers
- Data Acquisition System
- Vehicle-mounted mobile laboratory
- Five shop-ventilation free flow fans (1200 ft^3/min, 350 watt, 56-68 inches high, with 25-32 inch blades)
- Three small room circulation fans (400 ft^3/min, 24 in. high, 16 in. blades)
- Solenoid valves (Allied Products, part no. V2W318C-5)
- Tygon tubing (3/8 inches diameter)
- Duct seal compound
- Duct tape, 2-inch wide
- Bathroom towel (3½ ft x 2 ft)
- Thermocouples
- Portable weather station
- Barometer

2. AIR SAMPLERS

The MIRAN®, operating at a wavelength of 10.7 μm, a path length of 0.75 m, and a slit-width of 1 mm was used for air sampling. Readings from the MIRAN® were recorded on a data acquisition system which was located in a mobile laboratory (a High Mobility Multipurpose Wheeled Vehicle, HMMWV) adjacent to the building being tested. The MIRAN® was calibrated to detect concentrations as low as 500 parts per billion. Each MIRAN® was calibrated by using three standard concentrations of span gases and recording the voltage output from the MIRANs® when they were filled with each concentration. The values of voltages were plotted versus concentration and a least squares linear regression analysis was performed on the data for each MIRAN®. Complete calibration data and graphs showing the correlation equations is included in this appendix.

When testing the rowhouses, three MIRANs® were used. They were placed in the safe room, in the hallway on the second floor, and on the first floor. When testing the apartments and single family houses, four MIRANs® were used. They were placed in the two safe rooms, in the hallway on the second floor, and on the first floor.

The MIRANs® were placed on their casing, which is approximately eight inches high. The sample tube and particulate filter extended above the MIRAN® so that the air sample was drawn from a height of approximately 4 to 5 feet. Air sample data were recorded at intervals of 30 seconds, beginning when the tracer gas was released into the house. The measurements were transferred from the MIRAN® to a data acquisition system, and concentrations were displayed on a monitor. The sampling continued for at least 16 hours.

3. TRACER GAS

The tracer gas used in this testing was sulfur hexafluoride (SF_6), which was released at an initial concentration of 30 to 40 parts per million. The cylinder of SF_6 was connected to a series of mass flow controllers which regulated the amount of SF_6 going into the various rooms. Each mass flow controller was connected to a dissemination line with a solenoid valve attached to the end of the line. The solenoid valve was controlled by a switch which turns them on or off simultaneously. Dissemination line(s) were placed on the first floor, in the hallway on the second floor, and in each safe room. Additional lines were added if the desired concentration was not being achieved as the mixing occurred. The SF_6 was released through the lines by opening the solenoid valves until the desired concentration was achieved in each area of the house. The flow was controlled by mass flow controllers. When a uniform concentration was achieved in the entire house and safe rooms, the solenoid valves and the valve of the SF_6 cylinder were turned off.

Air was stirred continuously throughout each trial by five large floor fans (1200 ft^3/min) and three smaller fans (400 ft^3/min). Three of the large fans were placed on the first floor and two were placed on the second floor in the hallway. A small fan was placed in each of the safe rooms and in the room with the least amount of circulation.

4. METEOROLOGICAL CONDITIONS

The temperature, humidity, wind speed and direction, and barometric pressure were recorded in each experiment. The temperature (ambient and indoors) and humidity data were taken by thermocouples and logged every 10 minutes on the DAS. Wind and humidity readings were taken adjacent to the building and within the Aberdeen Proving Ground area, the latter by the Aberdeen Test Center Weather Office.

5. CHARACTERISTICS OF THE TEST SPACE

With the exception of the exterior doors and the door leading into the safe room, all doors of the house remained open for the purpose of achieving a uniform initial concentration. All windows were closed tightly and the HVAC system was turned off. Tubing and cables from the solenoid valves and air samplers were routed from the interior of the building to the mobile laboratory through one window raised about ½ inch. This space was sealed tightly with duct seal compound. The vent fans in the bathrooms remained off at all times, and if the house contained a fireplace, the damper remained closed. If the safe room was to be taped, the tape was applied on the outside of the door in overlapping strips so that no openings were visible around the door.

6. TEST PROCEDURES

Step 1 - Place the MIRANs in the designated areas of the building and turn them on. Zero the meter and connect the sample lines.

Step 2 - Place the solenoid valves in areas where SF_6 is to be disseminated.

Step 3 - Run dissemination lines into the house through a designated

window and connect them to the solenoid valves. Each dissemination line is connected to one of four mass flow controllers which regulate the flow of SF_6 into the safe rooms, the first floor, and the second floor. Check to ensure that each dissemination line is attached to the proper mass flow controller.

Step 4 - Run the MIRAN® signal lines from the data acquisition system to the MIRANs in the house. Each line is designated to a particular area inside the house.

Step 5 - Run thermocouples to the first and second floors of the house. Place another thermocouple outside of the house to measure the ambient temperature.

Step 6 - Set up portable weather station to monitor wind speed, direction.

Step 7 - Place the mixing fans in the house and turn them on. Check to see that each room has adequate circulation flow.

Step 8 - Check the MIRANs again and make sure the meter is on zero.

Step 9 - Close all windows in the house. Place duct seal compound on the window through which cables and tubing enter to seal the area tightly.

Step 10 - If the experimental plan requires the safe rooms to be sealed, place duct tape over the vents inside the safe room. Then close the door to the safe room and place a wet towel at the bottom of the door, forcing it under the door as much as possible. If the test requires that the saferoom door be sealed with tape, apply duct tape completely around the door from the outside, sealing the space between the door and the door frame. Stuff the tape into the crack as far as possible to ensure a good seal.

Step 11 - Check the house to ensure that no vents, windows, or doors remain open. Close all exterior doors and begin logging data on the DAS.

Step 12 - Turn on the cylinder of SF_6. Begin disseminating SF_6 by turning on the switch to the solenoid valves.

Step 13 - Monitor the concentration of SF_6 in the various rooms. When the concentration approaches 30 parts per million in any area, reduce the flow of the mass flow controller for that area.

Step 14 - When the entire house has a concentration between 30 and 40 parts per million, turn off the cylinder of SF_6. Let the dissemination lines purge for about 30 seconds. When the purge is complete, turn off the switch to the solenoid valves.

Step 15 - Record data on the meteorological conditions.

7. CALCULATIONS.

The natural log of the tracer gas concentration was plotted versus time. The formula applied to determine the air exchange rate was: $\ln C(t) = -A * T + \ln C(0)$ where A is the exchange rate in air changes per hour and T is the time in hours.

MIRAN® CALIBRATION DATA FOR SULFUR HEXAFLUORIDE

Barcode 35172 July 18, 1995

Concentration SF_6 = 203.4645252 * Voltage + 0.0769330453

Conc (ppm)	Scale Reading	Scale	Voltage (Vdc)	Calculated Conc
0	0	0.025	0	0.076933
0.513	0.07	0.025	0.00175	0.432995
17.36	0.34	0.25	0.085	17.37141
20.33	0.398	0.25	0.0995	20.32165

Regression Output:	
Constant:	0.0769330453
Std Err of Y Est:	0.07912
R Squared:	0.99996
No. of Observations:	4
Degrees of Freedom:	2
X Coefficient(s):	203.4645252
Std Err of Coef:	0.8604

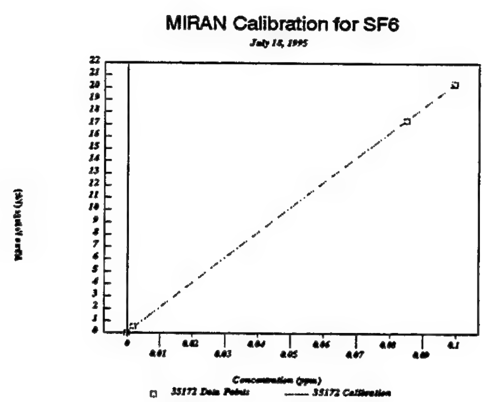

Figure A-1. MIRAN® 35172 Calibration

Barcode 13414 July 18, 1995

Concentration SF_6 = 155.97423629 * Voltage + 0.0460699758

Conc (ppm)	Scale Reading	Scale	Voltage (Vdc)	Calculated Conc
0	0	0.025	0	0.046069
0.513	0.1	0.025	0.0025	0.436005
17.36	0.45	0.25	0.1125	17.59317
20.33	0.515	0.25	0.12875	20.12775

Regression Output:

Constant:	0.0460699758
Std Err of Y Est:	0.22729
R Squared:	0.99970
No. of Observations:	4
Degrees of Freedom:	2
X Coefficient(s):	155.97423629
Std Err of Coef:	1.8951

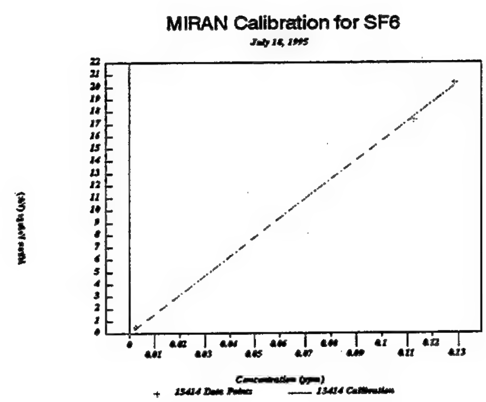

Figure A-2. MIRAN® 13414 Calibration

Barcode 4268 July 18, 1995

Concentration SF_6 = 284.061569 * Voltage - 0.039226672

Conc (ppm)	Scale Reading	Scale	Voltage (Vdc)	Calculated Conc
0	0.003	0.025	0.000075	-0.01792
0.0486	0.006	0.025	0.00015	0.003382
0.513	0.081	0.025	0.002025	0.535998
17.36	0.625	0.1	0.0625	17.71462
20.33	0.706	0.1	0.0706	20.01552

Regression Output:	
Constant:	-0.039226672
Std Err of Y Est:	0.27541
R Squared:	0.99946
No. of Observations:	5
Degrees of Freedom:	3
X Coefficient(s):	284.061569
Std Err of Coef:	3.8079555294

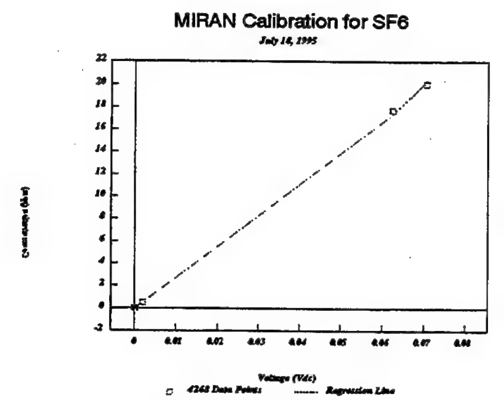

Figure A-3. MIRAN® 4268 Calibration

Barcode Chamber MIRAN July 25, 1995

Concentration SF_6 = 151.43744187 * Voltage

Conc (ppm)	Scale Reading	Scale	Voltage (Vdc)	Calculated Conc
0	0	0.025	0	0
0.513	0.122	0.025	0.00305	0.461884
17.36	0.455	0.25	0.11375	17.22600
20.33	0.54	0.25	0.135	20.44405

Regression Output:

Constant:	0
Std Err of Y Est:	0.10579
R Squared:	0.99990
No. of Observations:	4
Degrees of Freedom:	3
X Coefficient(s):	151.43744187
Std Err of Coef:	0.599176434

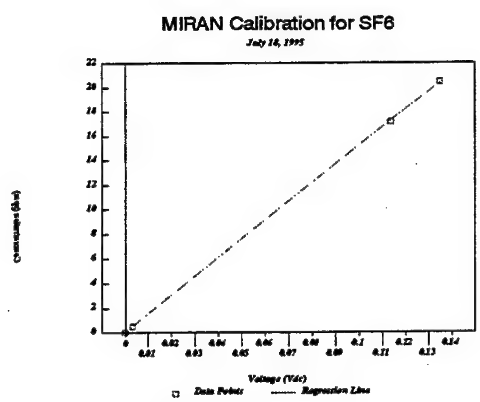

Figure A-4. MIRAN® Calibration

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APPENDIX D
WEATHER CONDITIONS DURING TESTS

Table D-1. Weather Data, 1330G - 19 Jul 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
7/19/95	1300	307	5.7	11.9	88.5	51
7/19/95	1400	312	5.7	13.5	88	51
7/19/95	1500	311	4.8	9.8	87.5	53
7/19/95	1600	313	4.7	10	87	53
7/19/95	1700	307	4	8.4	86.5	53
7/19/95	1800	316	3.9	8	84.5	54
7/19/95	1900	313	4	9.9	83	56
7/19/95	2000	327	2.1	5.7	78.9	67
7/19/95	2100	328	1.5	3.3	72.4	82
7/19/95	2200	302	1.4	3.9	70.3	91
7/19/95	2300	256	1.5	2.8	68.6	98
7/19/95	2359	284	2.3	5	68.2	99
7/20/95	0100	262	1.1	2.7	67	100
7/20/95	0200	290	0.8	2.4	65.8	100
7/20/95	0300	266	1	2.4	66.5	100
7/20/95	0400	339	1.2	4.7	67	100
7/20/95	0500	273	1	2.8	66.8	100
7/20/95	0600	293	1.2	2.5	67	100
7/20/95	0700	316	0.8	2.5	72.2	100

Table D-2. Weather Data, 1330G - 21 Jul 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
7/21/95	1300	21	7.8	12.8	86.6	89
7/21/95	1400	26	7.4	12.5	87	84
7/21/95	1500	33	7.4	13	88.7	73
7/21/95	1600	22	6.3	11.6	88	73
7/21/95	1700	19	5.2	9.2	84.4	78
7/21/95	1800	11	6.4	12.2	82.5	81
7/21/95	1900	16	6.2	11.7	81.9	80
7/21/95	2000	25	4.9	9.3	80.4	80
7/21/95	2100	294	2.3	6.7	77.2	84
7/21/95	2200	298	2.4	4.2	72.2	96
7/21/95	2300	330	2.9	6.2	72.8	97
7/21/95	2359	263	2.1	4.5	72	99
7/22/95	0100	315	1.7	4.1	71	100
7/22/95	0200	328	1.5	4.3	71.4	100
7/22/95	0300	310	1.1	4.3	72.1	100
7/22/95	0400	332	1.4	4	72.4	100
7/22/95	0500	24	3	8.2	72.2	100
7/22/95	0600	44	3.5	5.7	74.1	98
7/22/95	0700	29	4.8	8.4	76.6	97

Table D-3. Weather Data, 1330H - 25 Jul 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
7/25/95	1300	146	5.7	10.3	88.9	86
7/25/95	1400	154	5.7	10.5	90.5	81
7/25/95	1500	173	5.8	9.3	91.1	78
7/25/95	1600	171	5.4	10.7	90.6	83
7/25/95	1700	185	6.1	12.3	89.7	84
7/25/95	1800	196	7	12.3	88.2	85
7/25/95	1900	190	6.4	12.1	85.5	89
7/25/95	2000	192	6.2	12.6	84.5	95
7/25/95	2100	190	5.3	10.8	83.7	99
7/25/95	2200	173	3.9	7.4	83	100
7/25/95	2300	163	4	8.3	82.3	100
7/25/95	2359	161	5	9.3	82.1	100
7/26/95	0100	165	5	9.9	81.5	100
7/26/95	0200	181	5.1	9.6	81.8	100
7/26/95	0300	217	8.2	15.8	82.5	100
7/26/95	0400	213	5.4	9.8	81.2	100
7/26/95	0500	218	7.4	13.9	80.8	98
7/26/95	0600	246	7.1	14.6	80.6	97
7/26/95	0700	242	5.6	8.9	82	96

Table D-4. Weather Data, 1342 - 26 Jul 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
7/26/95	1400	194	6.4	12	88.3	86
7/26/95	1500	195	6.6	11.5	89.4	85
7/26/95	1600	242	7.4	13	92.2	73
7/26/95	1700	235	6.2	10.8	91.5	72
7/26/95	1800	245	3.8	7.3	90.5	74
7/26/95	1900	251	4.2	8.1	87.6	76
7/26/95	2000	312	2.3	5.2	84.1	85
7/26/95	2100	277	2.4	4.9	80.7	92
7/26/95	2200	248	3.3	5.3	80.1	92
7/26/95	2300	248	2.8	6.4	79.9	92
7/26/95	2359	332	0.9	2.4	77.1	98
7/27/95	0100	317	1.3	3	75.6	100
7/27/95	0200	296	1.7	6.3	76.1	100
7/27/95	0300	285	2	6.5	76.8	100
7/27/95	0400	308	0.2	1.8	74.3	100
7/27/95	0500	11	1.1	2.8	72.1	100
7/27/95	0600	301	1.4	3.4	73.3	100
7/27/95	0700	322	1.7	3.1	80.3	100

Table D-5. Weather Data, 1342 - 27 Jul 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
7/27/95	1300	172	6.9	12.8	91.9	84
7/27/95	1400	174	8	17.2	91.3	82
7/27/95	1500	194	8.6	27.3	88.6	84
7/27/95	1600	18	10	29	78.6	82
7/27/95	1700	69	2.6	9.7	83.6	92
7/27/95	1800	177	2.5	4.9	85.4	90
7/27/95	1900	194	4.9	10.7	85.8	91
7/27/95	2000	242	5	10.9	85.2	96
7/27/95	2100	269	1.8	5.4	81.2	100
7/27/95	2200	288	1.7	3.2	80.2	100
7/27/95	2300	246	10	22.4	78.7	100
7/27/95	2359	223	4.9	16.4	76.9	100
7/28/95	0100	276	1.5	3.3	75.5	100
7/28/95	0200	240	2.8	6.1	75.6	100
7/28/95	0300	246	5.9	10.7	77.5	100
7/28/95	0400	240	4.2	8.5	76.8	100
7/28/95	0500	212	5.5	11.7	76.8	100
7/28/95	0600	210	5.8	10.9	77.2	100
7/28/95	0700	211	7.8	15	78.5	100

Table D-6. Weather Data, 1342 - 28 Jul 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
7/28/95	1300	180	9.2	19.7	87.3	93
7/28/95	1400	189	11.3	20.6	87.4	90
7/28/95	1500	184	9.4	19.1	88.2	90
7/28/95	1600	192	12	24.4	89.6	86
7/28/95	1700	193	10.9	22.7	89.5	84
7/28/95	1800	203	12.6	24.9	87.4	84
7/28/95	1900	218	9.2	19.5	84.5	84
7/28/95	2000	220	7.4	13	82.9	90
7/28/95	2100	206	6.7	12.7	82.8	92
7/28/95	2200	196	6.9	12.4	83.3	91
7/28/95	2300	197	7.3	14	83.5	91
7/28/95	2359	211	10.1	18.1	83.6	90
7/29/95	0100	211	10.1	19.7	83.1	92
7/29/95	0200	216	10.9	18.5	82.3	92
7/29/95	0300	217	12.4	19.3	81.8	91
7/29/95	0400	216	10	17.1	80.7	93
7/29/95	0500	214	9.7	16.7	80.2	93
7/29/95	0600	214	10	15.5	79.9	93
7/29/95	0700	210	8.9	14.2	80.8	93

Table D-7. Weather Data, 1342 - 29 Jul 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
7/29/95	1200	174	8.6	14.9	88.4	90
7/29/95	1300	175	7.4	13.5	87.4	91
7/29/95	1400	178	7.8	15.5	89.9	90
7/29/95	1500	180	7.1	19.5	84.7	97
7/29/95	1600	194	6.4	14.6	86.5	98
7/29/95	1700	188	7.6	13.7	87.1	94
7/29/95	1800	191	6.6	12.6	87.7	94
7/29/95	1900	187	6.4	12.8	85.4	96
7/29/95	2000	202	5.4	15.4	83	99
7/29/95	2100	214	3.5	5.7	82.1	100
7/29/95	2200	214	3.1	5.3	81.5	100
7/29/95	2300	285	3.7	6.1	80.9	100
7/29/95	2359	296	4	7.6	80.8	95
7/30/95	0100	298	3.7	7.8	79.4	96
7/30/95	0200	298	4	7.7	78.6	95
7/30/95	0300	297	3.5	6	78	94
7/30/95	0400	312	3.4	6.8	77.4	93
7/30/95	0500	316	2.8	6.4	74.5	96
7/30/95	0600	302	2.9	4.9	75.3	96
7/30/95	0700	302	3.1	6.7	80.6	91

Table D-8. Weather Data, 1342 - 31 Jul 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
7/31/95	1300	141	4	8.3	92	54
7/31/95	1400	125	4.5	8.6	92.2	51
7/31/95	1500	136	3.2	6.9	93.2	52
7/31/95	1600	135	2.7	5.5	93.8	51
7/31/95	1700	117	2.1	4.8	93.3	51
7/31/95	1800	212	1.4	3	92.6	51
7/31/95	1900	279	1	2.4	87.4	62
7/31/95	2000	250	1.9	3.7	77.8	78
7/31/95	2100	213	3	5	75	81
7/31/95	2200	214	3.1	8.5	75.7	84
7/31/95	2300	176	5.7	10.5	79	83
7/31/95	2359	193	6.5	12.9	79.8	80
8/1/95	0100	206	6.9	12.2	80	83
8/1/95	0200	227	7.7	13.9	79.6	82
8/1/95	0300	231	7.1	13.1	78.7	84
8/1/95	0400	232	5.4	9.9	77.3	87
8/1/95	0500	241	4.1	9.1	75.7	90
8/1/95	0600	255	1.9	6.1	74	97
8/1/95	0700	217	5.2	9.1	80	93
8/1/95	0800	229	5.3	9	83.5	90

Table D-9. Weather Data, 1342 - 1 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/1/95	1300	168	7.3	13.5	90.3	79
8/1/95	1400	172	7.9	14.2	90.9	73
8/1/95	1500	174	8.1	14.5	90.5	78
8/1/95	1600	177	8.1	14.8	90.3	80
8/1/95	1700	180	7.6	14.4	89.5	82
8/1/95	1800	183	6.3	12.3	88.3	83
8/1/95	1900	187	6.3	11.6	86.9	84
8/1/95	2000	193	7.9	13.5	85.1	91
8/1/95	2100	196	9.1	15.9	84.3	96
8/1/95	2200	196	8.4	15.8	83.8	96
8/1/95	2300	194	9.4	16.3	83.6	96
8/1/95	2359	195	9.4	20	83	94
8/2/95	0100	205	9	15.5	82.4	92
8/2/95	0200	220	7.3	14.2	81.3	93
8/2/95	0300	221	6.3	11.2	80.2	95
8/2/95	0400	226	6.4	11.5	79.6	96
8/2/95	0500	226	5.9	11	78.9	98
8/2/95	0600	219	4.7	8.1	78.7	100
8/2/95	0700	220	6.6	10.8	81	98
8/2/95	0800	236	5.5	9.5	83.8	96

Table D-10. Weather Data, 1345 - 2 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/2/95	1400	182	7.6	16.8	93.8	73
8/2/95	1500	194	9.2	17.9	94.1	69
8/2/95	1600	193	8.6	15.6	93.6	71
8/2/95	1700	197	8.1	13.7	91.7	74
8/2/95	1800	190	6.3	11.5	89	80
8/2/95	1900	193	5.5	10.7	86.5	89
8/2/95	2000	191	5.8	11.1	85.4	91
8/2/95	2100	187	6.7	15.3	85.2	88
8/2/95	2200	189	8.4	19.4	84.7	88
8/2/95	2300	189	7.1	15.2	83.7	91
8/2/95	2359	194	6.6	13.4	82.9	92
8/3/95	0100	194	6.3	11.5	82.3	93
8/3/95	0200	194	6	12.7	82	96
8/3/95	0300	202	6.9	12.5	82.1	97
8/3/95	0400	218	6.1	11.1	81.3	96
8/3/95	0500	230	4.1	9.3	79.3	98
8/3/95	0600	234	2.6	7.1	78.7	100
8/3/95	0700	177	1.7	5.1	82.7	98
8/3/95	0800	222	3.2	7.5	86.1	93

Table D-11. Weather Data, 1345 - 3 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/3/95	1400	174	8.2	16.4	93.3	76
8/3/95	1500	193	9.7	16.7	93.8	72
8/3/95	1600	194	9.2	16.7	93	72
8/3/95	1700	194	9.4	16.7	91.4	72
8/3/95	1800	195	8.3	15.3	89.4	79
8/3/95	1900	194	8.8	14.8	86.9	83
8/3/95	2000	193	7.3	13.7	84.9	89
8/3/95	2100	188	7.9	16.6	84.3	90
8/3/95	2200	192	8.3	14.3	83.7	93
8/3/95	2300	194	9.4	16.6	83.3	92
8/3/95	2359	194	8.2	15.7	82.8	92
8/4/95	0100	197	7.6	15	82	95
8/4/95	0200	203	8.1	15.5	81.7	98
8/4/95	0300	217	6.5	13.1	80.9	98
8/4/95	0400	215	5.5	10	79.7	99
8/4/95	0500	219	5.4	9.8	78.9	100
8/4/95	0600	218	6.8	11.4	79.2	100
8/4/95	0700	222	6.9	11.3	81.9	99
8/4/95	0800	230	7.9	12.5	84.4	94

Table D-12. Weather Data, 1345 - 5 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/5/95	1200	142	5.7	10.7	89.1	85
8/5/95	1300	137	6	10.1	90.1	83
8/5/95	1400	154	6.3	11.4	91	82
8/5/95	1500	192	5	10.5	89.3	81
8/5/95	1600	256	7.8	25	84.1	88
8/5/95	1700	211	9.6	21.1	74.6	100
8/5/95	1800	208	7.4	16.7	77.4	100
8/5/95	1900	305	4.5	10.9	77.8	100
8/5/95	2000	312	3.8	7.1	76.2	100
8/5/95	2100	292	3.5	6.3	77.4	100
8/5/95	2200	276	5.1	10.9	77.8	100
8/5/95	2300	288	3.5	8.1	77.6	100
8/5/95	2359	312	2.1	4.4	76.5	100
8/6/95	0100	303	1.3	4.2	76.1	100
8/6/95	0200	274	1	3.6	76	100
8/6/95	0300	342	0.7	2.8	75.2	100
8/6/95	0400	21	2.7	7.8	75.2	100
8/6/95	0500	24	6	11.3	74.8	100
8/6/95	0600	10	6	13.8	72.9	100
8/6/95	0700	44	5.7	9.9	71.8	100

Table D-13. Weather Data, 3069 - 8 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/8/95	1300	59	7.5	12.8	77.7	76
8/8/95	1400	57	8.7	15.6	78.3	75
8/8/95	1500	69	6.8	11.8	76.7	77
8/8/95	1600	52	7.1	13.2	76.6	78
8/8/95	1700	78	5.6	9.6	76	79
8/8/95	1800	91	4.8	9.3	74.5	81
8/8/95	1900	107	4.5	7.6	73.3	82
8/8/95	2000	121	7.3	14.6	72.2	85
8/8/95	2100	121	7.7	14.4	70.9	89
8/8/95	2200	109	6.8	13	69.5	90
8/8/95	2300	99	5.7	10.6	68.1	92
8/8/95	2359	86	5.5	10.4	67.7	95
8/9/95	0100	80	4.2	8.7	67.6	98
8/9/95	0200	36	2.6	6.3	66.4	100
8/9/95	0300	29	4.1	7.7	66.3	100
8/9/95	0400	22	3.9	6.9	66	100
8/9/95	0500	30	3.6	6.4	65.8	100
8/9/95	0600	38	3.7	5.9	65.6	100
8/9/95	0700	33	3	6	67.3	100
8/9/95	0800	55	4.7	9.5	70.2	100

Table D-14. Weather Data, 3069 - 9 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/9/95	1300	76	3.5	9.7	78.8	87
8/9/95	1400	106	3.3	9.9	81.5	85
8/9/95	1500	108	3.4	8	81.1	84
8/9/95	1600	101	3.5	7.9	80.4	85
8/9/95	1700	84	3.7	6.4	79.4	86
8/9/95	1800	94	1.3	5.1	77.9	89
8/9/95	1900	100	2.6	5	75.8	92
8/9/95	2000	128	2.9	10.2	74.2	97
8/9/95	2100	122	7.6	13.3	74.4	97
8/9/95	2200	126	7.8	12.8	73.3	98
8/9/95	2300	141	8.7	15.7	72.6	98
8/9/95	2359	164	6.4	12.4	70.8	100
8/10/95	0100	167	2.9	6.5	70.3	100
8/10/95	0200	174	3.5	6.1	70.7	100
8/10/95	0300	182	2.4	4.9	70.6	100
8/10/95	0400	171	2.6	5.1	70.8	100
8/10/95	0500	157	3.3	7.2	70.8	100
8/10/95	0600	149	2.8	6.6	70.4	100
8/10/95	0700	146	4.2	8.5	74.3	99
8/10/95	0800	147	3.5	6.4	77.2	94

Table D-15. Weather Data, 3034 - 11 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/11/95	1300	153	3.1	7.4	88.2	80
8/11/95	1400	164	3.5	7.2	87.9	81
8/11/95	1500	233	5.1	8	87.6	80
8/11/95	1600	216	5.3	9.6	87.6	78
8/11/95	1700	203	5.6	9.5	85.9	79
8/11/95	1800	186	5.7	11.8	84.1	82
8/11/95	1900	189	3.5	7	81.9	88
8/11/95	2000	176	2.7	4.8	78.9	98
8/11/95	2100	167	3.3	6.8	77.6	100
8/11/95	2200	168	2.7	5.7	76.6	100
8/11/95	2300	174	1.8	4.3	75.4	100
8/11/95	2359	220	1.7	5	74.6	100
8/12/95	0100	239	2.3	4.3	74.3	100
8/12/95	0200	314	3.4	6.1	73.7	100
8/12/95	0300	315	2.7	7.1	71.9	100
8/12/95	0400	312	3.2	5.9	72.5	100
8/12/95	0500	320	3.2	4.8	71.1	100
8/12/95	0600	295	2.8	5.6	71.4	100
8/12/95	0700	291	4.2	7.5	75.2	100

Table D-16. Weather Data, 3034 - 14 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/14/95	1400	228	2.9	7.3	92.4	87
8/14/95	1500	146	5.4	8.6	90.6	91
8/14/95	1600	159	4.6	7.3	90.3	90
8/14/95	1700	161	3	6.2	88.8	94
8/14/95	1800	182	2.5	4.7	89.3	90
8/14/95	1900	169	2.1	4.4	86.1	96
8/14/95	2000	144	2.8	8.4	82.3	100
8/14/95	2100	133	2.6	7	81.1	100
8/14/95	2200	146	2.6	6.1	79.8	100
8/14/95	2300	176	3.5	10.3	80.1	100
8/14/95	2359	152	3.3	10.8	78.7	100
8/15/95	0100	161	4.7	11.5	77.4	97
8/15/95	0200	161	5.3	9.8	76.6	98
8/15/95	0300	174	4.2	7.7	76.3	99
8/15/95	0400	186	4.1	9.6	76.9	100
8/15/95	0500	83	2.3	5.1	75.8	100
8/15/95	0600	103	5.2	9.4	75.2	100
8/15/95	0700	137	4	12.6	75.3	100
8/15/95	0800	93	4.6	8	74.7	100

Table D-17. Weather Data, 1236 - 16 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/16/95	1600	87	7.4	11.8	90.3	85
8/16/95	1700	80	6.2	10.5	90.2	85
8/16/95	1800	68	4.2	7.2	88.9	86
8/16/95	1900	41	3	5.7	86	91
8/16/95	2000	22	3.1	5.8	82.6	94
8/16/95	2100	20	3.2	5.8	81.5	94
8/16/95	2200	14	3	5.4	80.3	96
8/16/95	2300	35	2.9	5.2	78.7	100
8/16/95	2359	24	3.7	8.4	78.3	100
8/17/95	0100	17	4.6	9.3	78.2	100
8/17/95	0200	7	5	11.5	78.3	100
8/17/95	0300	347	4.2	8.3	76.9	100
8/17/95	0400	11	5.2	10.4	77.2	100
8/17/95	0500	17	5.8	13.4	77.1	100
8/17/95	0600	34	7.4	14.4	76.8	100
8/17/95	0700	7	7.2	13.5	78.3	100
8/17/95	0800	14	8.3	15.7	81.3	98

Table D-18. Weather Data, 1236 - 17 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/17/95	1500	22	8.1	15	91.7	77
8/17/95	1600	20	7.1	13.3	91.4	76
8/17/95	1700	15	6.6	12.3	90.9	76
8/17/95	1800	16	6.5	12.3	89.3	77
8/17/95	1900	2	4.6	9.6	87.3	78
8/17/95	2000	348	3.1	6.1	84.8	82
8/17/95	2100	20	2.5	6.4	82.6	88
8/17/95	2200	275	1.3	2.7	78.1	98
8/17/95	2300	306	1.4	3.6	76.1	100
8/17/95	2359	353	3.3	6.9	78.4	99
8/18/95	0100	7	5	10	79.5	96
8/18/95	0200	345	4.4	9.5	78.2	94
8/18/95	0300	357	5	9.5	77.3	91
8/18/95	0400	345	4.2	8.5	76.3	89
8/18/95	0500	334	4.2	7.5	74.2	91
8/18/95	0600	343	4.7	8.6	74.5	89
8/18/95	0700	346	4.9	8.8	77.2	86

Table D-19. Weather Data, 1222 - 18 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/18/95	1500	17	6	10.3	92.9	59
8/18/95	1600	20	4.2	7.9	91.6	61
8/18/95	1700	3	2.5	6.7	88.8	68
8/18/95	1800	297	0.9	2.2	89.9	71
8/18/95	1900	278	0.8	1.6	84.9	85
8/18/95	2000	272	1.3	2.2	78	95
8/18/95	2100	132	8.8	17.5	79	85
8/18/95	2200	124	9.5	17.1	78.2	83
8/18/95	2300	107	7	12.8	76	87
8/18/95	2359	101	6.5	12.3	74.6	88
8/19/95	0100	97	5.4	9.6	73.9	89
8/19/95	0200	91	6.7	13.9	73.9	87
8/19/95	0300	81	8.1	15.2	73.7	82
8/19/95	0400	75	9.1	17.4	73.5	80
8/19/95	0500	56	6.9	14.3	72.9	81
8/19/95	0600	39	5.2	10.1	71.4	83
8/19/95	0700	33	5.1	11.1	72.1	81
8/19/95	0800	34	6.3	11.3	74.2	79

Table D-20. Weather Data, 1222 - 19 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/19/95	1200	75	4.8	9.3	81.5	71
8/19/95	1300	94	5.8	11	82.4	70
8/19/95	1400	92	4.3	9.4	84	69
8/19/95	1500	84	6.1	12.7	84.2	68
8/19/95	1600	90	6.9	12.4	83.7	67
8/19/95	1700	81	5.5	9.4	83.5	65
8/19/95	1800	96	4.7	10	81.4	65
8/19/95	1900	104	5	10.6	77.5	66
8/19/95	2000	127	8.3	15.3	74.9	74
8/19/95	2100	141	7.2	12.5	72.8	75
8/19/95	2200	132	5.3	9.5	71	78
8/19/95	2300	99	3.8	9.2	68.9	82
8/19/95	2359	87	5	9.6	68	83
8/20/95	0100	74	4.8	10.4	67.5	85
8/20/95	0200	32	3	6.3	65.2	93
8/20/95	0300	345	2.8	4.8	62.7	98
8/20/95	0400	308	1.1	3.3	59.6	100
8/20/95	0500	322	2.9	4.5	59.7	100
8/20/95	0600	341	2.1	6.1	60	100
8/20/95	0700	343	3.3	5.9	66.2	100
8/20/95	0800	16	4.5	9.2	70.8	93

Table D-21. Weather Data, 105 - 30 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/30/95	1300	143	4.6	6.6	83.2	42
8/30/95	1400	134	4.6	7	84.4	41
8/30/95	1500	149	4.7	7.3	85.1	41
8/30/95	1600	175	4.8	9.9	85.7	41
8/30/95	1700	171	4.6	7.3	85.2	41
8/30/95	1800	216	3.2	5.7	84	43
8/30/95	1900	245	3.5	5	78.9	54
8/30/95	2000	242	3.9	4.7	72.6	74
8/30/95	2100	254	3.8	6.3	69.2	94
8/30/95	2200	150	5.7	9.2	72.4	80
8/30/95	2300	189	8.2	13.4	70.5	81
8/30/95	2359	200	9	13.2	69.6	90
8/31/95	0100	196	6.7	11.6	69.2	93
8/31/95	0200	194	4.8	7.2	68.1	95
8/31/95	0300	205	3.8	5.7	67.3	99
8/31/95	0400	200	4.3	8.2	67.8	99
8/31/95	0500	186	4.5	8.4	68.5	99
8/31/95	0600	179	4.6	6.4	67.4	100
8/31/95	0700	197	5.4	8.3	68.9	99
8/31/95	0800	184	6.5	10.3	72.5	96

Table D-22. Weather Data, 105 - 31 Aug 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
8/31/95	1300	224	12.3	18.5	84.2	65
8/31/95	1400	220	12.6	17.8	85.3	64
8/31/95	1500	212	11.5	17	85.9	64
8/31/95	1600	210	10.7	15.2	86.6	63
8/31/95	1700	210	10.2	14.1	86.1	64
8/31/95	1800	205	10.1	14	84.1	67
8/31/95	1900	210	10.9	16.4	81.7	74
8/31/95	2000	207	11.1	15.3	80	78
8/31/95	2100	199	9.9	14.9	78	84
8/31/95	2200	202	9.2	13.8	77.1	88
8/31/95	2300	203	7.5	11.9	76.6	92
8/31/95	2359	211	8.1	14.1	77	94
9/1/95	0100	226	12.6	18.8	78.7	91
9/1/95	0200	230	12.3	18.5	78.5	91
9/1/95	0300	242	6.9	11.9	77.6	90
9/1/95	0400	266	4.6	7.4	76.1	93
9/1/95	0500	269	4.2	7	75.2	93
9/1/95	0600	316	4.2	7.2	75.8	89
9/1/95	0700	331	5.2	11.1	77.1	83
9/1/95	0800	350	9	16.2	79.1	74

Table D-23. Weather Data, 105 - 5 Sep 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
9/5/95	1300	216	8.2	12.4	82.3	54
9/5/95	1400	218	10	14.3	83.3	44
9/5/95	1500	216	9.9	15.1	84.3	41
9/5/95	1600	217	8.8	13.2	84.3	41
9/5/95	1700	217	7.5	11.4	83.6	42
9/5/95	1800	224	5.9	9.4	81.7	54
9/5/95	1900	235	4.8	7.6	77.9	65
9/5/95	2000	248	3.8	5.5	74.7	73
9/5/95	2100	244	4.5	8.2	73.8	84
9/5/95	2200	216	5.4	8.2	73	82
9/5/95	2300	219	6.3	9.9	72.2	86
9/5/95	2359	223	7.1	10.9	73.2	76
9/6/95	0100	229	7.1	10.9	72.6	78
9/6/95	0200	240	6.3	11.1	71.9	78
9/6/95	0300	241	4.2	7.5	70.3	83
9/6/95	0400	270	4.2	6.7	68.8	89
9/6/95	0500	298	4.3	6.4	68.1	94
9/6/95	0600	304	3.9	7.4	67.2	93
9/6/95	0700	7	5.9	9.1	70.4	83
9/6/95	0800	14	5.7	9.3	72.2	78

Table D-24. Weather Data, 105 - 6 Sep 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
9/6/95	1300	116	3.1	4.8	87.6	40
9/6/95	1400	101	3.1	4.6	88.7	32
9/6/95	1500	132	3.2	9.9	90.9	21
9/6/95	1600	213	7.2	9.5	88.2	26
9/6/95	1700	214	5.8	8.8	86.5	37
9/6/95	1800	214	5.1	6.9	83.3	42
9/6/95	1900	159	6.6	11.5	78.8	59
9/6/95	2000	134	7.2	11.4	77.5	67
9/6/95	2100	140	6.4	10	75.1	76
9/6/95	2200	168	7.8	10.4	72.7	83
9/6/95	2300	174	4.9	8.2	72.3	77
9/6/95	2359	188	2.6	5.2	70.2	84
9/7/95	0100	184	4.9	7.4	68.7	90
9/7/95	0200	191	5.8	8.2	68.2	95
9/7/95	0300	196	4	5.8	67.6	99
9/7/95	0400	210	3.8	6.1	67.7	98
9/7/95	0500	230	5.2	7.8	69.2	86
9/7/95	0600	226	5.6	8.6	69.5	84
9/7/95	0700	222	5.7	9	71	83

Table D-25. Weather Data, 54 - 8 Sep 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
9/8/95	1500	338	4	6.5	86	43
9/8/95	1600	353	6.3	13.9	83.5	54
9/8/95	1700	48	8.5	17.8	79.2	65
9/8/95	1800	83	12.4	19.3	75.9	79
9/8/95	1900	107	14.4	21.5	74.1	85
9/8/95	2000	95	10.1	17.4	73.6	88
9/8/95	2100	77	6.1	12	72.1	91
9/8/95	2200	74	5	8.4	71.5	94
9/8/95	2300	75	5.1	8.9	71.6	95
9/8/95	2359	87	5.4	10	71.2	95
9/9/95	0100	81	6.5	12.1	71.2	96
9/9/95	0200	96	8.4	13.2	70.7	97
9/9/95	0300	97	8.4	13.7	70.3	98
9/9/95	0400	85	6.7	11.3	70	97
9/9/95	0500	87	6.6	11.8	69.7	97
9/9/95	0600	90	6.2	11.2	69.5	97
9/9/95	0700	89	6.7	11.8	69.5	96
9/9/95	0800	101	7.7	12.7	70.3	94

Table D-26. Weather Data, 54 - 9 Sep 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
9/9/95	1400	56	3.6	5.5	81.4	61
9/9/95	1500	51	2.4	4.5	83.7	54
9/9/95	1600	51	2.5	4.1	83.9	53
9/9/95	1700	71	3.1	6.4	81.5	57
9/9/95	1800	61	4	8.4	79.5	63
9/9/95	1900	104	4.4	8.2	78.8	65
9/9/95	2000	125	5.1	9.7	77.4	69
9/9/95	2100	167	5.2	9.3	73.9	87
9/9/95	2200	178	4.8	6.9	71.9	92
9/9/95	2300	225	3.9	7.8	71.1	97
9/9/95	2359	335	6.5	15.2	71.3	98
9/10/95	0100	19	12.2	18.2	70.8	94
9/10/95	0200	20	16.4	26.8	69.6	80
9/10/95	0300	11	14.2	22.5	67.4	75
9/10/95	0400	8	14.7	21.6	65.8	70
9/10/95	0500	3	16.3	23.2	64.5	65
9/10/95	0600	7	14.8	24	63.8	64
9/10/95	0700	5	12.5	20.9	63.1	65
9/10/95	0800	2	14.2	22.5	63.8	65

Table D-27. Weather Data, 54 - 11 Sep 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
9/11/95	1300	0	4.8	7.4	70.5	45
9/11/95	1400	356	5.2	7.7	71.4	44
9/11/95	1500	12	4.5	6.5	73.1	43
9/11/95	1600	10	4.9	6.8	74.4	30
9/11/95	1700	9	4.4	6.8	74.9	30
9/11/95	1800	36	3.7	6.6	74.2	39
9/11/95	1900	123	9.1	15.4	69.9	53
9/11/95	2000	149	12.2	18.8	66.7	65
9/11/95	2100	164	11.3	18.2	64.7	67
9/11/95	2200	171	11.9	18.3	63.2	69
9/11/95	2300	186	5.2	12	62	72
9/11/95	2359	179	6.8	10.8	61.1	75
9/12/95	0100	214	5.4	9.4	60.7	79
9/12/95	0200	187	7.5	10.2	59.7	82
9/12/95	0300	200	4.7	7.5	58.4	87
9/12/95	0400	208	5.1	6.9	58.4	86
9/12/95	0500	216	3.6	7.1	58.2	88
9/12/95	0600	162	2.9	5	58.9	78
9/12/95	0700	166	3.5	4.8	60.4	74
9/12/95	0800	162	4.7	7.5	65.2	68

Table D-28. Weather Data, 54 - 12 Sep 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
9/12/95	1300	218	5	8.4	75.6	39
9/12/95	1400	228	5.4	9.2	76.9	39
9/12/95	1500	224	5.3	10.4	78.1	39
9/12/95	1600	229	7.4	11.2	74.2	43
9/12/95	1700	234	5.5	9.9	72.6	43
9/12/95	1800	230	6.2	9.9	71.9	51
9/12/95	1900	199	5.4	8	70.4	62
9/12/95	2000	192	6.3	9.1	68.8	62
9/12/95	2100	192	6.1	9.7	68.6	60
9/12/95	2200	195	7.2	10.7	68.7	57
9/12/95	2300	196	7.4	11.1	68.1	65
9/12/95	2359	201	9	12.9	68.3	69
9/13/95	0100	190	9.1	13.5	68.4	76
9/13/95	0200	191	8.8	13.7	68.4	84
9/13/95	0300	192	8.7	12.5	68.3	89
9/13/95	0400	190	7.2	10.1	67.8	94
9/13/95	0500	189	7.8	11.7	68.3	96
9/13/95	0600	196	9.4	13.5	69.2	94
9/13/95	0700	209	13.3	21.1	71	87
9/13/95	0800	214	15.1	21.8	72.2	82

Table D-29. Weather Data, 54 - 13 Sep 95

Date	Time	Avg Wind Dir (°)	Avg Wind Speed (mph)	Peak Wind Speed (mph)	Average Temp (°F)	Relative Humidity (%)
9/13/95	1300	220	13	18.4	82.7	60
9/13/95	1400	218	10.7	16.4	84	57
9/13/95	1500	214	9.6	14.5	85	56
9/13/95	1600	220	7.2	11.1	84.7	58
9/13/95	1700	204	4.4	7.1	81.6	65
9/13/95	1800	209	4.6	6.8	79.6	69
9/13/95	1900	275	6.7	26.8	75.8	83
9/13/95	2000	282	5.7	15.7	72.9	97
9/13/95	2100	137	2.8	5.1	72.4	98
9/13/95	2200	204	3.7	6.2	72	99
9/13/95	2300	249	2.5	4.4	71.6	100
9/13/95	2359	192	3	4.3	71.3	100
9/14/95	0100	233	2.9	6.7	71.1	100
9/14/95	0200	224	8	13	72.4	100
9/14/95	0300	234	6.9	12.2	72.6	98
9/14/95	0400	229	5.1	7.1	71.4	99
9/14/95	0500	227	5.1	7.2	71	99
9/14/95	0600	224	6.6	11.4	70.9	99
9/14/95	0700	232	7.5	12.2	71.7	98

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APPENDIX E
TABLES OF RESULTS

Table E-1. Air Exchange Rates Measured in Experiments Conducted 25 Jul - 17 Aug

House, room	Date	Inside/outside temperature difference (°F)	Sealing Measures on saferoom	Air exchange rate of whole house (ACH)	Air exchange rate of safe room (ACH)
1330H dnstairs bath	25 Jul	5.2	towel, taped vent	0.282	--
1330H upstairs bath	25 Jul	7.0	towel, taped vent	0.180	0.210
1330G upstairs bath	19 Jul	1.5	none (as is)	0.190	0.276
1330G upstairs bath	21 Jul	2.9	towel, taped vent	0.177	0.192
1342 upstairs bath	26 Jul	3.2	none (as is)	0.296	0.200
1342 upstairs closet	26 Jul	5.5	none (as is)	0.296	0.176
1342 upstairs bath	27 Jul	--	towel, taped vent	0.377	0.235
1342 upstairs closet	27 Jul	--	towel, taped vent	0.377	0.371
1342 upstairs bath	28 Jul	5.1	none (as is)	0.191	0.114
1342 upstairs bath	28 Jul	5.8	none (as is)	0.191	0.116
1342 upstairs bath	29 Jul	8.9	towel, taped vent	0.366	0.193
1342 upstairs bath	29 Jul	9.8	towel, taped vent	0.366	0.171
1342 upstairs bath	31 Jul	11.7	towel, taped vent	0.389	0.245
1342 upstairs closet	31 Jul	12.8	towel, taped vent	0.389	0.176
1342 upstairs bath	1 Aug	8.0	none (as is)	0.240	0.109
1345 upstairs bath	2 Aug	5.8	none (as is)	0.456	0.415
1345 upstairs closet	2 Aug	8.9	none (as is)	0.456	0.365
1345 upstairs bath	3 Aug	6.9	towel, taped vent	0.428	0.226
1345 upstairs closet	3 Aug	8.2	towel, taped vent	0.428	0.259
1345 upstairs bath	5 Aug	--	none (as is)	0.827	0.861
1345 upstairs bath	5 Aug	--	none (as is)	0.827	0.818
3069 dnstairs bath	8 Aug	9.7	none (as is)	0.318	0.316
3069 upstairs bath	8 Aug	11.5	none (as is)	0.317	0.318
3069 dnstairs bath	9 Aug	7.3	towel, taped vent	0.203	0.188
3069 upstairs bath	9 Aug	9.0	towel, taped vent	0.211	0.149
3034 dnstairs bath	11 Aug	6.4	none (as is)	0.364	0.384
3034 upstairs bath	11 Aug	9.4	none (as is)	0.368	0.347
3034 dnstairs bath	14 Aug	7.1	towel, taped vent	0.329	0.288
3034 upstairs bath	14 Aug	10.2	towel, taped vent	0.352	0.308
1236 upstairs bath	16 Aug	3.7	none (as is)	0.166	0.174
1236 upstairs bath	16 Aug	6.3	none (as is)	0.166	0.165
1236 upstairs bath	17 Aug	4.6	towel, taped vent	0.167	0.162
1236 upstairs bath	17 Aug	7.6	towel, taped vent	0.167	0.162

Note: Where the two safe rooms in the experiment were both on the second floor, the whole house air exchange rate measured upstairs is listed twice.

Table E-2. Air Exchange Rates Measured in Experiments Conducted 18 Aug - 19 Oct

House, room	Date	Inside/outside temperature difference (°F)	Sealing Measures on saferoom	Air exchange rate of whole house (ACH)	Air exchange rate of safe room (ACH)
1222 upstairs bath	18 Aug	5.8	none (as is)	0.673	0.682
1222 upstairs closet	18 Aug	6.6	none (as is)	0.673	0.582
1222 upstairs bath	19 Aug	9.4	towel, taped vent	0.581	0.386
1222 upstairs closet	19 Aug	10.5	towel, taped vent	0.581	0.460
105 downstairs bath	30 Aug	5.6	none (as is)	0.413	0.260
105 upstairs bath	30 Aug	7.9	none (as is)	0.273	0.328
105 downstairs bath	31 Aug	2.7	towel, taped vent	0.231	0.210
105 upstairs bath	31 Aug	5.3	towel, taped vent	0.250	0.212
105 downstairs bath	5 Sep	6.0	towel, taped vent	0.364	0.295
105 upstairs bath	5 Sep	9.1	towel, taped vent	0.368	0.323
105 downstairs bath	6 Sep	5.9	towel, tape, sheet	0.376	0.295
105 upstairs bath	6 Sep	9.2	towel, tape, sheet	0.395	0.310
54 downstairs bath	8 Sep	7.1	none (as is)	0.213	0.150
54 upstairs bath	8 Sep	9.2	none (as is)	0.210	0.203
54 downstairs bath	9 Sep	10.6	towel, tape, sheet	0.230	0.120
54 upstairs bath	9 Sep	12.9	towel, tape, sheet	0.229	0.171
54 downstairs bath	11 Sep	13.1	towel, taped vent	0.241	0.166
54 upstairs bath	11 Sep	14.8	towel, taped vent	0.237	0.194
54 downstairs bath	12 Sep	6.7	none (as is)	0.245	0.249
54 upstairs closet	12 Sep	8.3	none (as is)	0.266	0.159
54 downstairs	13 Sep	3.4	none (as is)	0.199	0.172
54 upstairs closet	13 Sep	5.4	towel, tape,	0.210	0.149
E4587 mobile home*	6 Oct	7.5	none (as is)	0.459	0.443
E4587 mobile home*	8 Oct	15.2	towel, taped vent	0.479	0.357
E4587 mobile home*	7 Oct	21.1	towel, tape, sheet	0.462	0.236
T5354 mobile home*	17 Oct	9.8	none (as is)	0.582	0.487
T5354 mobile home*	18 Oct	8.9	towel, taped vent	0.541	0.458
T5354 mobile home*	19 Oct	5.2	towel, taped door	0.343	0.148

* bathroom used as safe room in each mobile home

Note: Where the two safe rooms in the experiment were both on the second floor, the whole house air exchange rate measured upstairs is listed twice.

Bldg 1330G Trial 1, 19 Jul 95

Bathroom
A= 0.068 air changes per hour

Regression Output:

Constant	2.117203
Std Err of Y Est	0.077466
R Squared	0.882977
No. of Observations	3923
Degrees of Freedom	3921
X Coefficient(s)	-0.06762
Std Err of Coef.	0.000393

House
A= 0.154 air changes per hour

Regression Output:

Constant	3.918902
Std Err of Y Est	0.065648
R Squared	0.982049
No. of Observations	3923
Degrees of Freedom	3921
X Coefficient(s)	-0.15431
Std Err of Coef.	0.000333

Bldg 1330G Trial 2, 20 Jul 95

Bathroom
A= 0.192 air changes per hour

Regression Output:

Constant	
Std Err of Y Est	0.062916
R Squared	0.980751
No. of Observations	1944
Degrees of Freedom	1942
X Coefficient(s)	-0.19196
Std Err of Coef.	0.000610

House
A= 0.177 air changes per hour

Regression Output:

Constant	1.395150
Std Err of Y Est	0.033832
R Squared	0.993356
No. of Observations	1944
Degrees of Freedom	1942
X Coefficient(s)	-0.17683
Std Err of Coef.	0.000328

Bldg 1330G Trial 3, 21 Jul 95

Bathroom
A= 0.276 air changes per hour

Regression Output:

Constant	5.384119
Std Err of Y Est	0.035040
R Squared	0.987083
No. of Observations	923
Degrees of Freedom	921
X Coefficient(s)	-0.27557
Std Err of Coef.	0.001038

Hallway
A= 0.190 air changes per hour

Regression Output:

Constant	4.306182
Std Err of Y Est	0.015633
R Squared	0.984813
No. of Observations	549
Degrees of Freedom	547
X Coefficient(s)	-0.19024
Std Err of Coef.	0.001010

Bldg 1330H Trial 1, 24 Jul 95

Bathroom
A= 0.376 air changes per hour

Regression Output:

Constant	7.491726
Std Err of Y Est	0.159718
R Squared	0.958761
No. of Observations	1701
Degrees of Freedom	1699
X Coefficient(s)	-0.37618
Std Err of Coef.	0.001892

Hallway, 2nd Floor
A= 0.068 Air changes per hour

Regression Output:

Constant	2.670784
Std Err of Y Est	0.052278
R Squared	0.953225
No. of Observations	2881
Degrees of Freedom	2879
X Coefficient(s)	-0.06808
Std Err of Coef.	0.000281

1st Floor, Living Room, 1330G
A= 0.039 Air changes per hour

Regression Output:

Constant	1.835814
Std Err of Y Est	0.022530
R Squared	0.953178
No. of Observations	2173
Degrees of Freedom	2171
X Coefficient(s)	-0.03887
Std Err of Coef.	0.000184

Hallway, 2nd Floor, 1330H
A= 0.180 Air changes per hour

Regression Output:

Constant	4.650075
Std Err of Y Est	0.070871
R Squared	0.981861
No. of Observations	2401
Degrees of Freedom	2399
X Coefficient(s)	-0.18047
Std Err of Coef.	0.000500

Bldg 1330H Trial 2, 25 Jul 95

Bathroom sealed
A= 0.210 Air changes per hour

Regression Output:

Constant	4.665316
Std Err of Y Est	0.149412
R Squared	0.913397
No. of Observations	1921
Degrees of Freedom	1919
X Coefficient(s)	-0.20989
Std Err of Coef.	0.001475

1st Floor, Living Room
A= 0.282 Air changes per hour

Regression Output:

Constant	6.362450
Std Err of Y Est	0.063091
R Squared	0.912819
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.28194
Std Err of Coef.	0.003560

Bldg 1342B Trial 1, 26 Jul 95

Bathroom, No window, unsealed
A= 0.200 Air changes per hour

Regression Output:

Constant	5.763412
Std Err of Y Est	0.011324
R Squared	0.998026
No. of Observations	1059
Degrees of Freedom	1057
X Coefficient(s)	-0.19972
Std Err of Coef.	0.000273

Walk-in Closet, unsealed
A= 0.176 Air changes per hour

Regression Output:

Constant	5.363636
Std Err of Y Est	0.014288
R Squared	0.995957
No. of Observations	1059
Degrees of Freedom	1057
X Coefficient(s)	-0.17591
Std Err of Coef.	0.000344

1st Floor, Living Room
A= 0.349 Air changes per hour

Regression Output:

Constant	9.083023
Std Err of Y Est	0.031487
R Squared	0.995005
No. of Observations	1059
Degrees of Freedom	1057
X Coefficient(s)	-0.34856
Std Err of Coef.	0.000759

Hallway, 2nd Floor
A= 0.296 Air changes per hour

Regression Output:

Constant	7.690329
Std Err of Y Est	0.025689
R Squared	0.995382
No. of Observations	1059
Degrees of Freedom	1057
X Coefficient(s)	-0.29583
Std Err of Coef.	0.000619

Bldg 1342B Trial 2, 27 Jul 95

Windowless Bathroom, sealed
A= 0.235 Air changes per hour

Regression Output:

Constant	5.752418
Std Err of Y Est	0.037014
R Squared	0.988293
No. of Observations	1201
Degrees of Freedom	1199
X Coefficient(s)	-0.23523
Std Err of Coef.	0.000739

1st Floor, Living Room
A= 0.366 Air changes per hour

Regression Output:

Constant	8.712785
Std Err of Y Est	0.050203
R Squared	0.993797
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.36638
Std Err of Coef.	0.000763

Walk-in Closet, sealed
A= 0.371 Air changes per hour

Regression Output:

Constant	9.256876
Std Err of Y Est	0.073995
R Squared	0.994132
No. of Observations	2160
Degrees of Freedom	2158
X Coefficient(s)	-0.37054
Std Err of Coef.	0.000612

Hallway, 2nd Floor
A= 0.377 Air changes per hour

Regression Output:

Constant	8.511959
Std Err of Y Est	0.064658
R Squared	0.990340
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.37747
Std Err of Coef.	0.000982

Bldg 1342B Trial 3, 28 Jul 95

Windowless Bathroom, not sealed
A= 0.116 Air changes per hour

Regression Output:

Constant	3.121447
Std Err of Y Est	0.078581
R Squared	0.948256
No. of Observations	2401
Degrees of Freedom	2399
X Coefficient(s)	-0.11643
Std Err of Coef.	0.000555

Bathroom with window, not sealed
A= 0.114 Air changes per hour

Regression Output:

Constant	3.244401
Std Err of Y Est	0.090125
R Squared	0.930178
No. of Observations	2401
Degrees of Freedom	2399
X Coefficient(s)	-0.11385
Std Err of Coef.	0.000636

1st Floor, Living Room
A= 0.235 Air changes per hour

Regression Output:

Constant	5.647727
Std Err of Y Est	0.084737
R Squared	0.984693
No. of Observations	2401
Degrees of Freedom	2399
X Coefficient(s)	-0.23524
Std Err of Coef.	0.000598

Hallway, 2nd Floor
A= 0.191 Air changes per hour

Regression Output:

Constant	4.487145
Std Err of Y Est	0.101345
R Squared	0.967413
No. of Observations	2401
Degrees of Freedom	2399
X Coefficient(s)	-0.19112
Std Err of Coef.	0.000716

Bldg 1342B Trial 4, 29 Jul 95

Windowless Bathroom sealed
A= 0.171 Air changes per hour

Regression Output:

Constant	4.454448
Std Err of Y Est	0.030576
R Squared	0.989531
No. of Observations	1445
Degrees of Freedom	1443
X Coefficient(s)	-0.17092
Std Err of Coef.	0.000462

Bathroom with window, sealed
A= 0.193 Air changes per hour

Regression Output:

Constant	4.964693
Std Err of Y Est	0.050601
R Squared	0.977791
No. of Observations	1445
Degrees of Freedom	1443
X Coefficient(s)	-0.19304
Std Err of Coef.	0.000765

1st Floor, Living Room
A= 0.405 Air changes per hour

Regression Output:

Constant	9.448716
Std Err of Y Est	0.087060
R Squared	0.984951
No. of Observations	1445
Degrees of Freedom	1443
X Coefficient(s)	-0.40496
Std Err of Coef.	0.001317

Hallway, 2nd Floor
A= 0.366 Air changes per hour

Regression Output:

Constant	8.280125
Std Err of Y Est	0.109314
R Squared	0.971283
No. of Observations	1445
Degrees of Freedom	1443
X Coefficient(s)	-0.36552
Std Err of Coef.	0.001654

Bldg 1342B Trial 5, 31 Jul 95

Windowless Bathroom, sealed
A= 0.245 Air changes per hour

Regression Output:

Constant	6.238377
Std Err of Y Est	0.056012
R Squared	0.988961
No. of Observations	1801
Degrees of Freedom	1799
X Coefficient(s)	-0.24460
Std Err of Coef.	0.000609

Walk-in Closet, sealed
A= 0.176 Air changes per hour

Regression Output:

Constant	5.782629
Std Err of Y Est	0.025204
R Squared	0.986074
No. of Observations	1001
Degrees of Freedom	999
X Coefficient(s)	-0.17597
Std Err of Coef.	0.000661

1st Floor, Living Room
A= 0.369 Air changes per hour

Regression Output:

Constant	9.067121
Std Err of Y Est	0.068427
R Squared	0.992723
No. of Observations	1801
Degrees of Freedom	1799
X Coefficient(s)	-0.36873
Std Err of Coef.	0.000744

Hallway, 2nd Floor
A= 0.389 Air changes per hour

Regression Output:

Constant	9.139645
Std Err of Y Est	0.126120
R Squared	0.978137
No. of Observations	1801
Degrees of Freedom	1799
X Coefficient(s)	-0.38920
Std Err of Coef.	0.001371

Bldg 1342B Trial 6, 1 Aug 95

Windowless Bathroom, sealed
A= 0.109 Air changes per hour

Regression Output:

Constant	3.218604
Std Err of Y Est	0.041677
R Squared	0.973432
No. of Observations	1922
Degrees of Freedom	1920
X Coefficient(s)	-0.10906
Std Err of Coef.	0.000411

1st Floor, Living Room
A= 0.222 Air changes per hour

Regression Output:

Constant	5.596170
Std Err of Y Est	0.046433
R Squared	0.991900
No. of Observations	1922
Degrees of Freedom	1920
X Coefficient(s)	-0.22215
Std Err of Coef.	0.000458

Hallway, 2nd Floor
A= 0.240 Air changes per hour

Regression Output:

Constant	5.738034
Std Err of Y Est	0.079514
R Squared	0.979849
No. of Observations	1922
Degrees of Freedom	1920
X Coefficient(s)	-0.23972
Std Err of Coef.	0.000784

Bldg 1345A Trial 1, 2 Aug 95

Windowless Bathroom, not sealed
A= 0.415 Air changes per hour

Regression Output:

Constant	11.42451
Std Err of Y Est	0.018050
R Squared	0.998591
No. of Observations	961
Degrees of Freedom	959
X Coefficient(s)	-0.41541
Std Err of Coef.	0.000503

Walk-in Closet, not sealed
A= 0.365 Air changes per hour

Regression Output:

Constant	10.43218
Std Err of Y Est	0.022437
R Squared	0.997191
No. of Observations	961
Degrees of Freedom	959
X Coefficient(s)	-0.36538
Std Err of Coef.	0.000626

1st Floor, Living Room
A= 0.403 Air changes per hour

Regression Output:

Constant	10.66888
Std Err of Y Est	0.013671
R Squared	0.999142
No. of Observations	961
Degrees of Freedom	959
X Coefficient(s)	-0.40333
Std Err of Coef.	0.000381

Hallway, 2nd Floor
A= 0.456 Air changes per hour

Regression Output:

Constant	12.07192
Std Err of Y Est	0.010734
R Squared	0.999586
No. of Observations	961
Degrees of Freedom	959
X Coefficient(s)	-0.45627
Std Err of Coef.	0.000299

Bldg 1345A Trial 2, 3 Aug 95

Windowless Bathroom, sealed
A= 0.226 Air changes per hour

Regression Output:

Constant	6.786190
Std Err of Y Est	0.092625
R Squared	0.969531
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.22593
Std Err of Coef.	0.001055

Walk-in Closed, sealed
A= 0.259 Air changes per hour

Regression Output:

Constant	8.795453
Std Err of Y Est	0.022559
R Squared	0.994390
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.25939
Std Err of Coef.	0.000726

1st Floor, Living Room
A= 0.414 Air changes per hour

Regression Output:

Constant	11.02546
Std Err of Y Est	0.040773
R Squared	0.998187
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.41370
Std Err of Coef.	0.000464

Hallway, 2nd Floor
A= 0.428 Air changes per hour

Regression Output:

Constant	11.68621
Std Err of Y Est	0.073832
R Squared	0.994478
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.42846
Std Err of Coef.	0.000841

Bldg 1345A Trial 3, 5 Aug 95

Windowless Bathroom, sealed
A= 0.818 Air changes per hour

Regression Output:

Constant	16.47701
Std Err of Y Est	0.052518
R Squared	0.996932
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.81768
Std Err of Coef.	0.001691

1st Floor, Living Room
A= 0.855 Air changes per hour

Regression Output:

Constant	16.56588
Std Err of Y Est	0.058895
R Squared	0.996472
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.85482
Std Err of Coef.	0.001896

Walk-in Closet, sealed
A= 0.861 Air changes per hour

Regression Output:

Constant	17.13605
Std Err of Y Est	0.045266
R Squared	0.997943
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.86114
Std Err of Coef.	0.001457

Hallway, 2nd Floor
A= 0.827 Air changes per hour

Regression Output:

Constant	16.39951
Std Err of Y Est	0.073487
R Squared	0.994139
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.82662
Std Err of Coef.	0.002366

Bldg 3069 Trial 1, 8 Aug 95

Windowless Bathroom, not sealed
A= 0.316 Air changes per hour

Regression Output:

Constant	10.11702
Std Err of Y Est	0.027424
R Squared	0.998595
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.31622
Std Err of Coef.	0.000312

1st Floor, Living Room
A= 0.318 Air changes per hour

Regression Output:

Constant	10.27988
Std Err of Y Est	0.029586
R Squared	0.998380
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.31766
Std Err of Coef.	0.000337

Bathroom with window, unsealed
A= 0.318 Air changes per hour

Regression Output:

Constant	10.31510
Std Err of Y Est	0.047882
R Squared	0.995780
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.31808
Std Err of Coef.	0.000545

Hallway, 2nd Floor
A= 0.317 Air changes per hour

Regression Output:

Constant	10.16899
Std Err of Y Est	0.029466
R Squared	0.998387
No. of Observations	1441
Degrees of Freedom	1439
X Coefficient(s)	-0.31704
Std Err of Coef.	0.000335

Bldg 3069 Trial 2, 9 Aug 95

Bathroom with window, sealed
A= 0.188 Air changes per hour

Regression Output:

Constant	6.721301
Std Err of Y Est	0.016219
R Squared	0.997536
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.18789
Std Err of Coef.	0.000348

Windowless Bathroom, sealed
A= 0.149 Air changes per hour

Regression Output:

Constant	5.881753
Std Err of Y Est	0.012845
R Squared	0.990337
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.14933
Std Err of Coef.	0.000778

1st Floor, Living Room
A= 0.203 Air changes per hour

Regression Output:

Constant	7.193342
Std Err of Y Est	0.022238
R Squared	0.996039
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.20304
Std Err of Coef.	0.000477

Hallway, 2nd Floor
A= 0.211 Air changes per hour

Regression Output:

Constant	7.232722
Std Err of Y Est	0.022317
R Squared	0.996308
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.21108
Std Err of Coef.	0.000479

Bldg 3034 Trial 1, 11 Aug 95

Bathroom with window, not sealed
A= 0.384 Air changes per hour

Regression Output:

Constant	12.50450
Std Err of Y Est	0.035432
R Squared	0.995963
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.38431
Std Err of Coef.	0.000999

Windowless Bathroom, not sealed
A= 0.347 Air changes per hour

Regression Output:

Constant	12.01608
Std Err of Y Est	0.007943
R Squared	0.999750
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.34747
Std Err of Coef.	0.000224

1st Floor, Living Room
A= 0.364 Air changes per hour

Regression Output:

Constant	12.36097
Std Err of Y Est	0.012810
R Squared	0.999409
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.36388
Std Err of Coef.	0.000361

Hallway, 2nd Floor
A= 0.368 Air changes per hour

Regression Output:

Constant	12.25809
Std Err of Y Est	0.013123
R Squared	0.999393
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.36784
Std Err of Coef.	0.000370

Bldg 3034 Trial 2, 12 Aug 95

Bathroom No window
A= 0.336 Air changes per hour

Regression Output:

Constant	11.05524
Std Err of Y Est	0.026011
R Squared	0.998549
No. of Observations	844
Degrees of Freedom	842
X Coefficient(s)	-0.33568
Std Err of Coef.	0.000440

Bathroom, with window
A= 0.364 Air changes per hour

Regression Output:

Constant	12.06729
Std Err of Y Est	0.032455
R Squared	0.998076
No. of Observations	844
Degrees of Freedom	842
X Coefficient(s)	-0.36372
Std Err of Coef.	0.000550

1st Floor, Living Room
A= 0.324 Air changes per hour

Regression Output:

Constant	10.92573
Std Err of Y Est	0.022783
R Squared	0.998802
No. of Observations	844
Degrees of Freedom	842
X Coefficient(s)	-0.32362
Std Err of Coef.	0.000386

Hallway, 2nd Floor
A= 0.373 Air changes per hour

Regression Output:

Constant	11.96892
Std Err of Y Est	0.035396
R Squared	0.997821
No. of Observations	844
Degrees of Freedom	842
X Coefficient(s)	-0.37264
Std Err of Coef.	0.000600

Bldg 3034 Trial 3, 13 Aug 95

Bathroom with window, not sealed
A= 0.345 Air changes per hour

Regression Output:

Constant	12.93807
Std Err of Y Est	0.054698
R Squared	0.981653
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.34506
Std Err of Coef.	0.002155

Windowless Bathroom, no sealed
A= 0.348 Air changes per hour

Regression Output:

Constant	13.85326
Std Err of Y Est	0.014165
R Squared	0.998767
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.34776
Std Err of Coef.	0.000558

1st Floor, Living Room
A= 0.338 Air changes per hour

Regression Output:

Constant	13.35241
Std Err of Y Est	0.009438
R Squared	0.999420
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.33802
Std Err of Coef.	0.000371

Hallway, 2nd Floor
A= 0.382 Air changes per hour

Regression Output:

Constant	14.49467
Std Err of Y Est	0.011636
R Squared	0.999310
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.38204
Std Err of Coef.	0.000458

Bldg 3034 Trial 4, 14 Aug 95

Bathroom with window, sealed
A= 0.288 Air changes per hour

Regression Output:

Constant	9.616783
Std Err of Y Est	0.095278
R Squared	0.964986
No. of Observations	722
Degrees of Freedom	720
X Coefficient(s)	-0.28758
Std Err of Coef.	0.002041

Windowless Bathroom, sealed
A= 0.308 Air changes per hour

Regression Output:

Constant	10.88869
Std Err of Y Est	0.020121
R Squared	0.998588
No. of Observations	722
Degrees of Freedom	720
X Coefficient(s)	-0.30772
Std Err of Coef.	0.000431

1st Floor, Living Room
A= 0.329 Air changes per hour

Regression Output:

Constant	11.37056
Std Err of Y Est	0.024884
R Squared	0.998114
No. of Observations	722
Degrees of Freedom	720
X Coefficient(s)	-0.32918
Std Err of Coef.	0.000533

Hallway, 2nd Floor
A= 0.352 Air changes per hour

Regression Output:

Constant	11.74278
Std Err of Y Est	0.031931
R Squared	0.997281
No. of Observations	722
Degrees of Freedom	720
X Coefficient(s)	-0.35164
Std Err of Coef.	0.000684

Bldg 1236 Trial 1, 16 Aug 95

Bathroom w/ window, 2 doors, unsealed
A= 0.174 Air changes per hour

Regression Output:

Constant	6.886078
Std Err of Y Est	0.022259
R Squared	0.994594
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.17385
Std Err of Coef.	0.000477

Bathroom with window, not sealed
A= 0.165 Air changes per hour

Regression Output:

Constant	6.952998
Std Err of Y Est	0.026592
R Squared	0.991491
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.16527
Std Err of Coef.	0.000570

1st Floor, Living Room
A= 0.163 Air changes per hour

Regression Output:

Constant	6.315022
Std Err of Y Est	0.029048
R Squared	0.989567
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.16288
Std Err of Coef.	0.000623

Hallway, 2nd Floor
A= 0.166 Air changes per hour

Regression Output:

Constant	6.420187
Std Err of Y Est	0.021586
R Squared	0.994409
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.16575
Std Err of Coef.	0.000463

Bldg 1236 Trial 2, 17 Aug 95

Bathroom w/ window, 2 doors, sealed
A= 0.162 Air changes per hour

Regression Output:

Constant	6.515319
Std Err of Y Est	0.013411
R Squared	0.994954
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.16243
Std Err of Coef.	0.000528

Bathroom with window, sealed
A= 0.162 Air changes per hour

Regression Output:

Constant	6.739571
Std Err of Y Est	0.012800
R Squared	0.995380
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.16204
Std Err of Coef.	0.000504

1st Floor, Living Room
A= 0.170 Air changes per hour

Regression Output:

Constant	6.386018
Std Err of Y Est	0.021605
R Squared	0.988096
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.16976
Std Err of Coef.	0.000851

Hallway, 2nd Floor
A= 0.167 Air changes per hour

Regression Output:

Constant	6.223159
Std Err of Y Est	0.014963
R Squared	0.994088
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.16735
Std Err of Coef.	0.000589

Bldg 1222 Trial 1, 18 Aug 95

Bathroom with window, not sealed
A= 0.682 Air changes per hour

Regression Output:

Constant	18.03905
Std Err of Y Est	0.039179
R Squared	0.995662
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.68162
Std Err of Coef.	0.002374

Walk In Closet, not sealed
A= 0.582 Air changes per hour

Regression Output:

Constant	16.54529
Std Err of Y Est	0.029999
R Squared	0.996514
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.58244
Std Err of Coef.	0.001818

1st Floor, Living Room
A= 0.657 Air changes per hour

Regression Output:

Constant	17.67222
Std Err of Y Est	0.013262
R Squared	0.999462
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.65695
Std Err of Coef.	0.000803

Hallway, 2nd Floor
A= 0.673 Air changes per hour

Regression Output:

Constant	17.57149
Std Err of Y Est	0.012781
R Squared	0.999524
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.67297
Std Err of Coef.	0.000774

Bldg 1222 Trial 2, 19 Aug 95

Bathroom with window, sealed
A= 0.386 Air changes per hour

Regression Output:

Constant	9.970090
Std Err of Y Est	0.037426
R Squared	0.993040
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.38556
Std Err of Coef.	0.001474

Walk In Closet, sealed
A= 0.460 Air changes per hour

Regression Output:

Constant	11.86444
Std Err of Y Est	0.024505
R Squared	0.997889
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.45956
Std Err of Coef.	0.000965

1st Floor, Living Room
A= 0.608 Air changes per hour

Regression Output:

Constant	14.79861
Std Err of Y Est	0.027298
R Squared	0.998501
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.60764
Std Err of Coef.	0.001075

Hallway, 2nd Floor
A= 0.581 Air changes per hour

Regression Output:

Constant	13.73505
Std Err of Y Est	0.036077
R Squared	0.997137
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.58068
Std Err of Coef.	0.001421

Bldg A105 Trial 1, 30 Aug 95

Bathroom with window, not sealed
A= 0.260 Air changes per hour

Regression Output:

Constant	9.248874
Std Err of Y Est	0.013660
R Squared	0.998380
No. of Observations	541
Degrees of Freedom	539
X Coefficient(s)	-0.26013
Std Err of Coef.	0.000451

Bathroom with window, not sealed
A= 0.328 Air changes per hour

Regression Output:

Constant	10.63118
Std Err of Y Est	0.042637
R Squared	0.990172
No. of Observations	541
Degrees of Freedom	539
X Coefficient(s)	-0.32824
Std Err of Coef.	0.001408

1st Floor, Living Room
A= 0.413 Air changes per hour

Regression Output:

Constant	12.12624
Std Err of Y Est	0.059140
R Squared	0.984118
No. of Observations	468
Degrees of Freedom	466
X Coefficient(s)	-0.41263
Std Err of Coef.	0.002428

Hallway, 2nd Floor
A= 0.273 Air changes per hour

Regression Output:

Constant	9.268368
Std Err of Y Est	0.025085
R Squared	0.995061
No. of Observations	541
Degrees of Freedom	539
X Coefficient(s)	-0.27310
Std Err of Coef.	0.000828

Bldg A105 Trial 2, 31 Aug 95

Bathroom with window, sealed
A= 0.210 Air changes per hour

Regression Output:

Constant	7.462327
Std Err of Y Est	0.020624
R Squared	0.998210
No. of Observations	961
Degrees of Freedom	959
X Coefficient(s)	-0.21045
Std Err of Coef.	0.000287

Bathroom with window, sealed
A= 0.212 Air changes per hour

Regression Output:

Constant	7.437906
Std Err of Y Est	0.012234
R Squared	0.999381
No. of Observations	961
Degrees of Freedom	959
X Coefficient(s)	-0.21242
Std Err of Coef.	0.000170

1st Floor, Living Room
A= 0.231 Air changes per hour

Regression Output:

Constant	7.545505
Std Err of Y Est	0.009037
R Squared	0.999713
No. of Observations	961
Degrees of Freedom	959
X Coefficient(s)	-0.23053
Std Err of Coef.	0.000126

Hallway, 2nd Floor
A= 0.250 Air changes per hour

Regression Output:

Constant	7.991197
Std Err of Y Est	0.022041
R Squared	0.998551
No. of Observations	961
Degrees of Freedom	959
X Coefficient(s)	-0.25008
Std Err of Coef.	0.000307

Bldg A105 Trial 3, 5 Sep 95

Bathroom with window, sealed
A= 0.295 Air changes per hour

Regression Output:

Constant	9.641694
Std Err of Y Est	0.028196
R Squared	0.996975
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.29476
Std Err of Coef.	0.000605

Bathroom with window, sealed
A= 0.323 Air changes per hour

Regression Output:

Constant	10.18610
Std Err of Y Est	0.023378
R Squared	0.998268
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.32315
Std Err of Coef.	0.000501

1st Floor, Living Room
A= 0.364 Air changes per hour

Regression Output:

Constant	10.10161
Std Err of Y Est	0.020256
R Squared	0.998975
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.36424
Std Err of Coef.	0.000434

Hallway, 2nd Floor
A= 0.368 Air changes per hour

Regression Output:

Constant	10.29031
Std Err of Y Est	0.028040
R Squared	0.998080
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.36816
Std Err of Coef.	0.000602

Bldg A105 Trial 4, 6 Sep 95

Bathroom with window, Method 2
A= 0.295 Air changes per hour

Regression Output:

Constant	9.040377
Std Err of Y Est	0.032567
R Squared	0.994216
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.29484
Std Err of Coef.	0.000918

Bathroom with window, sealed
A= 0.310 Air changes per hour

Regression Output:

Constant	9.241804
Std Err of Y Est	0.029339
R Squared	0.995736
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.30960
Std Err of Coef.	0.000827

1st Floor, Living Room
A= 0.376 Air changes per hour

Regression Output:

Constant	9.878485
Std Err of Y Est	0.021158
R Squared	0.998491
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.37590
Std Err of Coef.	0.000596

Hallway, 2nd Floor
A= 0.395 Air changes per hour

Regression Output:

Constant	10.39804
Std Err of Y Est	0.032369
R Squared	0.996813
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.39533
Std Err of Coef.	0.000913

Bldg A-54 Trial 1, 8 Sep 95

Bathroom with window, not sealed
A= 0.150 Air changes per hour

Regression Output:

Constant	5.248532
Std Err of Y Est	0.037843
R Squared	0.988284
No. of Observations	962
Degrees of Freedom	960
X Coefficient(s)	-0.15003
Std Err of Coef.	0.000527

Bathroom with window, not sealed
A= 0.203 Air changes per hour

Regression Output:

Constant	6.749194
Std Err of Y Est	0.016122
R Squared	0.999261
No. of Observations	1211
Degrees of Freedom	1209
X Coefficient(s)	-0.20336
Std Err of Coef.	0.000159

1st Floor, Living Room
A= 0.213 Air changes per hour

Regression Output:

Constant	6.616167
Std Err of Y Est	0.027022
R Squared	0.998106
No. of Observations	1211
Degrees of Freedom	1209
X Coefficient(s)	-0.21281
Std Err of Coef.	0.000266

Hallway, 2nd Floor
A= 0.210 Air changes per hour

Regression Output:

Constant	6.563814
Std Err of Y Est	0.025818
R Squared	0.998222
No. of Observations	1211
Degrees of Freedom	1209
X Coefficient(s)	-0.20987
Std Err of Coef.	0.000254

Bldg A-54 Trial 2, 9 Sep 95

Bathroom with window, Method 2
A= 0.120 Air changes per hour

Regression Output:

Constant	5.632406
Std Err of Y Est	0.016418
R Squared	0.993880
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.12047
Std Err of Coef.	0.000352

1st Floor, Living Room
A= 0.230 Air changes per hour

Regression Output:

Constant	6.877097
Std Err of Y Est	0.015020
R Squared	0.998588
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.22999
Std Err of Coef.	0.000322

Bathroom with window, Method 2
A= 0.171 Air changes per hour

Regression Output:

Constant	6.334012
Std Err of Y Est	0.018509
R Squared	0.996148
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.17140
Std Err of Coef.	0.000397

Hallway, 2nd Floor
A= 0.229 Air changes per hour

Regression Output:

Constant	6.847884
Std Err of Y Est	0.017413
R Squared	0.998085
No. of Observations	721
Degrees of Freedom	719
X Coefficient(s)	-0.22891
Std Err of Coef.	0.000373

Bldg A-54 Trial 3, 11 Sep 95

Bathroom with window, Method 1
A= 0.166 Air changes per hour

Regression Output:

Constant	5.597485
Std Err of Y Est	0.018422
R Squared	0.983997
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.16588
Std Err of Coef.	0.001116

1st Floor, Living Room
A= 0.241 Air changes per hour

Regression Output:

Constant	6.689824
Std Err of Y Est	0.010807
R Squared	0.997364
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.24140
Std Err of Coef.	0.000655

Bathroom with window, Method 1
A= 0.194 Air changes per hour

Regression Output:

Constant	6.279352
Std Err of Y Est	0.010782
R Squared	0.995939
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.19391
Std Err of Coef.	0.000653

Hallway, 2nd Floor
A= 0.237 Air changes per hour

Regression Output:

Constant	6.608994
Std Err of Y Est	0.009615
R Squared	0.997843
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.23749
Std Err of Coef.	0.000582

Bldg A-54 Trial 4, 12 Sep 95

Bathroom with window, not sealed
A= 0.249 Air changes per hour

Regression Output:

Constant	6.832807
Std Err of Y Est	0.087228
R Squared	0.970928
No. of Observations	841
Degrees of Freedom	839
X Coefficient(s)	-0.24887
Std Err of Coef.	0.001486

1st Floor, Living Room
A= 0.245 Air changes per hour

Regression Output:

Constant	6.750064
Std Err of Y Est	0.033609
R Squared	0.995422
No. of Observations	841
Degrees of Freedom	839
X Coefficient(s)	-0.24469
Std Err of Coef.	0.000572

Walk-in closet, not sealed
A= 0.159 Air changes per hour

Regression Output:

Constant	5.383226
Std Err of Y Est	0.035095
R Squared	0.988220
No. of Observations	841
Degrees of Freedom	839
X Coefficient(s)	-0.15870
Std Err of Coef.	0.000598

Hallway, 2nd Floor
A= 0.266 Air changes per hour

Regression Output:

Constant	7.157063
Std Err of Y Est	0.037389
R Squared	0.995213
No. of Observations	841
Degrees of Freedom	839
X Coefficient(s)	-0.26615
Std Err of Coef.	0.000637

Bldg A-54 Trial 5, 13 Sep 95

Bathroom with window, not sealed
A= 0.172 Air changes per hour

Regression Output:

Constant	5.472677
Std Err of Y Est	0.024922
R Squared	0.984646
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.17212
Std Err of Coef.	0.000982

1st Floor, Living Room
A= 0.199 Air changes per hour

Regression Output:

Constant	5.935922
Std Err of Y Est	0.009364
R Squared	0.998358
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.19919
Std Err of Coef.	0.000369

Walk-in closed, sealed
A= 0.149 Air changes per hour

Regression Output:

Constant	5.224566
Std Err of Y Est	0.008631
R Squared	0.997496
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.14860
Std Err of Coef.	0.000340

Hallway, 2nd Floor
A= 0.210 Air changes per hour

Regression Output:

Constant	6.064519
Std Err of Y Est	0.011194
R Squared	0.997896
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.21026
Std Err of Coef.	0.000441

Trailer E4587 Trial 1, 6 Oct 95

Bathroom with window, unsealed
A= 0.443 Air changes per hour

Regression Output:

Constant	11.91823
Std Err of Y Est	0.025554
R Squared	0.997534
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.44326
Std Err of Coef.	0.001006

Main office area
A= 0.459 Air changes per hour

Regression Output:

Constant	12.15305
Std Err of Y Est	0.030798
R Squared	0.996668
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.45944
Std Err of Coef.	0.001213

Area adjacent to bathroom
A= 0.454 Air changes per hour

Regression Output:

Constant	12.07006
Std Err of Y Est	0.028755
R Squared	0.997025
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.45400
Std Err of Coef.	0.001133

Trailer E4587 Trial 2, 7 Oct 95

Bathroom with window, Method 2 sealing
A= 0.236 Air changes per hour

Regression Output:

Constant	6.497795
Std Err of Y Est	0.061064
R Squared	0.978327
No. of Observations	722
Degrees of Freedom	720
X Coefficient(s)	-0.23589
Std Err of Coef.	0.001308

Main office area
A= 0.462 Air changes per hour

Regression Output:

Constant	6.354768
Std Err of Y Est	0.030798
R Squared	0.996668
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.46235
Std Err of Coef.	0.001213

Area adjacent to bathroom
A= 0.457 Air changes per hour

Regression Output:

Constant	7.382649
Std Err of Y Est	0.028755
R Squared	0.997025
No. of Observations	481
Degrees of Freedom	479
X Coefficient(s)	-0.45679
Std Err of Coef.	0.001133

Trailer E4587 Trial 3, 8 Oct 95

Bathroom with window, Method 1 sealing
A= 0.357 Air changes per hour

Regression Output:

Constant	7.270988
Std Err of Y Est	0.074356
R Squared	0.940801
No. of Observations	344
Degrees of Freedom	342
X Coefficient(s)	-0.35715
Std Err of Coef.	0.004844

Main office area
A= 0.479 Air changes per hour

Regression Output:

Constant	10.22233
Std Err of Y Est	0.022832
R Squared	0.997010
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.47879
Std Err of Coef.	0.001383

Area adjacent to bathroom
A= 0.496 Air changes per hour

Regression Output:

Constant	10.57754
Std Err of Y Est	0.031472
R Squared	0.994720
No. of Observations	361
Degrees of Freedom	359
X Coefficient(s)	-0.49607
Std Err of Coef.	0.001907

Trailer T5354 Trial 1, 17 Oct 95

Windowless Bathroom, not sealed
A= 0.487 Air changes per hour

Regression Output:

Constant	11.41395
Std Err of Y Est	0.015117
R Squared	0.998737
No. of Observations	362
Degrees of Freedom	360
X Coefficient(s)	-0.48684
Std Err of Coef.	0.000912

Main office area, outside bathroom
A= 0.702 Air changes per hour

Regression Output:

Constant	15.28011
Std Err of Y Est	0.058233
R Squared	0.991059
No. of Observations	362
Degrees of Freedom	360
X Coefficient(s)	-0.70210
Std Err of Coef.	0.003514

Area near entryway
A= 0.582 Air changes per hour

Regression Output:

Constant	13.07913
Std Err of Y Est	0.015469
R Squared	0.999074
No. of Observations	362
Degrees of Freedom	360
X Coefficient(s)	-0.58214
Std Err of Coef.	0.000933

Trailer T5354 Trial 2, 18 Oct 95

Windowless Bathroom, Method 1 sealing
A= 0.458 Air changes per hour
Regression Output:

Constant	10.64739
Std Err of Y Est	0.054654
R Squared	0.991724
No. of Observations	542
Degrees of Freedom	540
X Coefficient(s)	-0.45803
Std Err of Coef.	0.001800

Main office area, outside bathroom
A= 0.541 Air changes per hour
Regression Output:

Constant	12.27074
Std Err of Y Est	0.024226
R Squared	0.997419
No. of Observations	365
Degrees of Freedom	363
X Coefficient(s)	-0.54096
Std Err of Coef.	0.001444

Area near entryway
A= 0.550 Air changes per hour
Regression Output:

Constant	12.18004
Std Err of Y Est	0.024806
R Squared	0.997381
No. of Observations	365
Degrees of Freedom	363
X Coefficient(s)	-0.54986
Std Err of Coef.	0.001478

Trailer T5354 Trial 3, 19 Oct 95

Windowless Bathroom, Method 2 sealing
A= 0.148 Air changes per hour
Regression Output:

Constant	2.982502
Std Err of Y Est	0.057486
R Squared	0.932926
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.14804
Std Err of Coef.	0.001621

Main office area, outside bathroom
A= 0.343 Air changes per hour

Regression Output:

Constant	7.896020
Std Err of Y Est	0.013369
R Squared	0.999274
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.34265
Std Err of Coef.	0.000377

Area near entryway
A= 0.400 Air changes per hour

Regression Output:

Constant	8.625671
Std Err of Y Est	0.023687
R Squared	0.998334
No. of Observations	601
Degrees of Freedom	599
X Coefficient(s)	-0.40044
Std Err of Coef.	0.000668

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APPENDIX F
PROCEDURES RECOMMENDED FOR EXPEDIENT SHELTERING IN PLACE

1. Preparations for Sheltering:

a. For the greatest possible protection, select a "safe room" of your home or building in advance and store a kit of expedient sheltering materials in or near this room for use in an emergency.

b. Select the room that has the least number of windows and that has adequate space for the number of people to be sheltered. About 10 square feet of floor space is needed for each person. For four people, the room should have 40 square feet of area (for example, 5 ft by 8 ft or 6 ft by 7 ft).

c. The room can be upstairs or downstairs but it should not be in the basement.

d. The room should have an electrical outlet so that you can plug in a radio or television to receive emergency instructions.

e. If the light in the room works only with a ventilation fan (as is the case in some bathrooms), take a plug-in lamp for light so that the ventilation fan can remain off.

f. Your kit of sheltering supplies should contain: a roll of two-inch wide cloth tape (duct tape), plastic sheeting such as a polyethylene drop cloth adequate to cover each window of the safe room, a radio, a container of water, a small amount of non-perishable food, one towel for each door.

2. Instructions for Sheltering in an Emergency.

a. If you are not already indoors, go indoors and close all windows and doors. If you have pets, bring them indoors also. Lock the windows to achieve the tightest seal possible. If there is a fireplace, extinguish the fire and close the damper.

b. Turn off *all* air conditioning, heating, and ventilating systems.

c. Go into your selected safe room.

d. If you have a portable indoor air purifier that contains a carbon (black) filter element, take it into the room with you and turn it on. Once inside, close the door and seal the room as follows:

(1) Wet a towel and place it at the base of the door to seal the gap between the door and the floor.

(2) Place two-inch wide cloth tape (duct tape) around the door to seal the space between the door and its frame.

(3) Place a plastic sheet (such as a polyethylene drop cloth) over the window. Starting at the top, place a continuous, overlapping strips of tape at the edges of all four sides to seal the window.

(4) Place duct tape over any vents, such as the ventilation fan opening, gaps around pipes that come through the wall, or electrical outlets.

e. Turn on a radio or television and listen for emergency instructions.

f. Wait calmly for emergency instructions and leave the telephone lines open if emergency information is to be transmitted by telephone.

g. You will receive instructions about when it is safe to vacate your home or building. Once you are told it is safe to come out of your shelter, do not delay. Open all windows and doors as you exit.